VOLUME 39 CHEMICAL & METALLURGICAL ENGINEERING NUMBER 4

ESTABLISHED 1902—McGRAW-HILL PUBLISHING COMPANY, INC.

S. D. KIRKPATRICK, Editor

April, 1932

WHAT FUEL, AND HOW EFFICIENT?

ON April 7, 1826, a distinguished pioneer in fuel research in this country read a memoir before the American Philosophical Society of Philadelphia, to which he affixed this scholarly title:

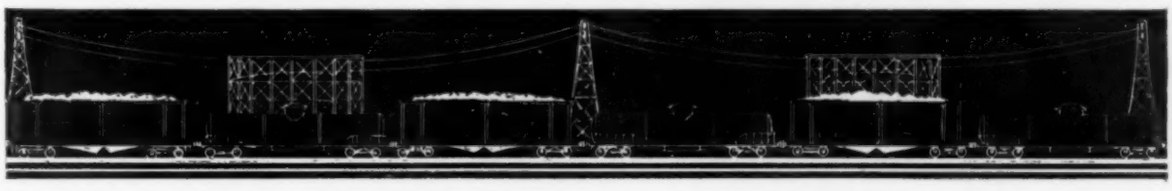
"Experiments to determine the comparative quantities of heat evolved in the combustion of the principal varieties of wood and coal used in the United States for fuel, and also to determine the comparative quantities of heat lost by the ordinary apparatus made use of for their combustion."

The question for which Mr. Marcus Bull so diligently sought an answer more than a hundred years ago is even more pertinent today. The extension of natural-gas pipe lines has called for a complete reconsideration of fuel purchasing habits in many great industrial areas. Similar growth in the supplies of liquefied petroleum gases, propane and butane, and of the gaseous byproducts of oil refining, is further extending the problems of fuel selection and utilization. Electric energy was never more widely or more economically distributed. Critical and continuing study of fuel and energy application is the order of the day.

Chem. and Met. has undertaken in this issue to present to the chemical engineers of America a composite of basic information on fuels and energy, interpreted by authorities in each field. The application of heat and power is a common denominator of industry, a unit operation of vital interest to widely diverse fields. The reader will, it is hoped, be able to translate from the best of existing practice of others many ideas that will properly fit into new but similar situations in his own industry. On the other hand, each industrial heating problem must be considered primarily in terms of the ideal results to be obtained. Far too many comparisons are made merely on a cost or thermal efficiency basis. More should be made on a basis of over-all accomplishment in the heating process.

Proper selection of fuel and power sources has not always had the attention it deserves. Chemical engineers responsible for both the quality and cost of products in the process industries should recognize as fundamental the basic principle that the value of the fuel is in the service it renders. Next comes the ease of application and control, including the working conditions the fuel creates in the plant in which it is used. Last, but not always most important, is the question of cost in relation to all of these factors. Choice of method, of heating equipment, or of the fuel itself is secondary to the chemical engineer's prime objective: a better product.

The pages that follow present, first, the overall picture of the fuel and energy supply of American industry, followed by more detailed consideration of the requirements of the process group. Then a brief statement of certain fundamental concepts of industrial heating serves to introduce a comprehensive series of articles on heat technology—from steam and power generation to control and utilization. Replete with practical applications as well as basic principles and data, this issue should prove a useful tool for the chemical engineer who seeks the present-day answer to one of industry's oldest problems.



INTER-FUEL and INTER-ENERGY COMPETITION

for AMERICAN INDUSTRY'S $2,000,000,000 HEAT and POWER BILL

SELECTION of fuel or energy supply for an industrial operation should begin with a precise determination of the ideal thermal processing required. From this ideal objective in plant operation one should work backward through process control, selection of equipment, and finally reach a choice of fuel or energy source. By this means, and this only, does the engineer gain a precise yardstick for gaging the merits of competing fuel supplies which may be offered to him for selection.

Almost invariably coal in its raw state will afford the lowest-cost fuel source if judged solely on the basis of heat or power available per dollar of material cost. Obviously, the use of such a yardstick alone in fuel selection is wholly unwarranted. The cost of fuel and of its use in securing a satisfactory end product should be measured by all of the consequences, both direct and indirect, which result from any particular choice. Cleanliness of plant may be, and in food plants usually is, a determining factor in choice. Controlability becomes a dominant consideration whenever extremely precise heating or power control is essential for the manufacture of a satisfactory product. In such instances, gas and electricity offer advantages which may far outweigh considerations of their higher cost per unit of energy purchased. In still other

Manufacturing Industries Spent $1,973,863,269 for Fuel and Energy in 1929

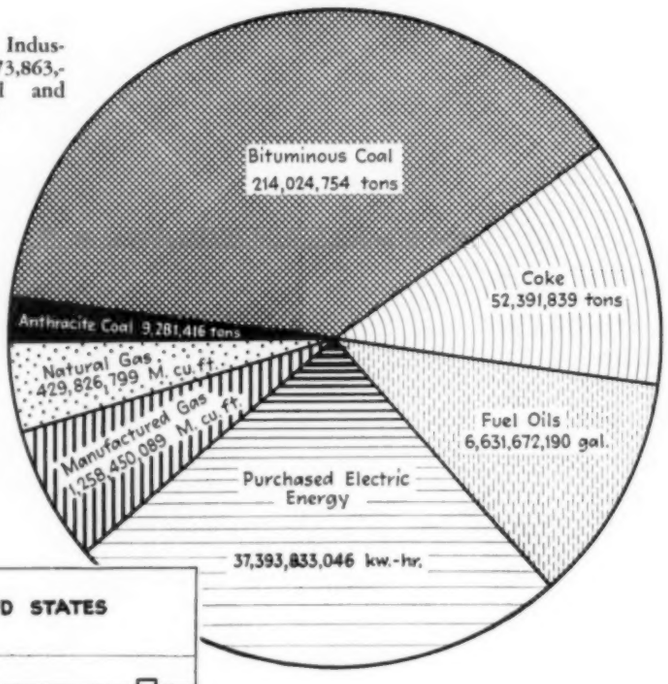
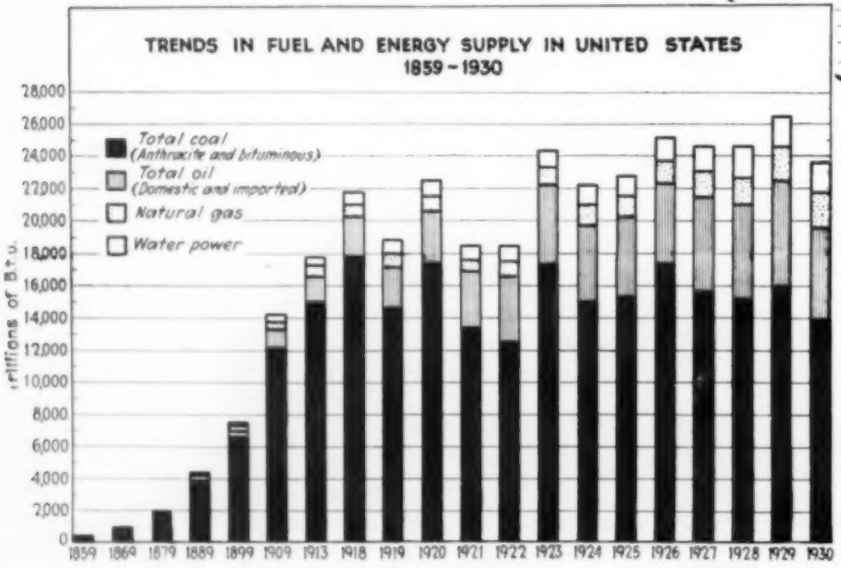
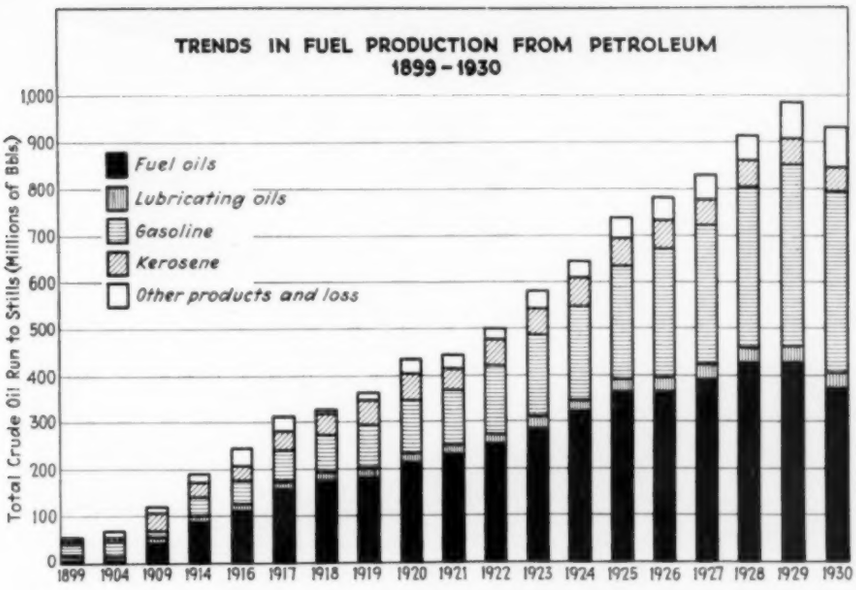


Chart below taken from data compiled by F. G. Tryon of U. S. Bureau of Mines, with fuel equivalent of water power calculated from reported horsepower of installations

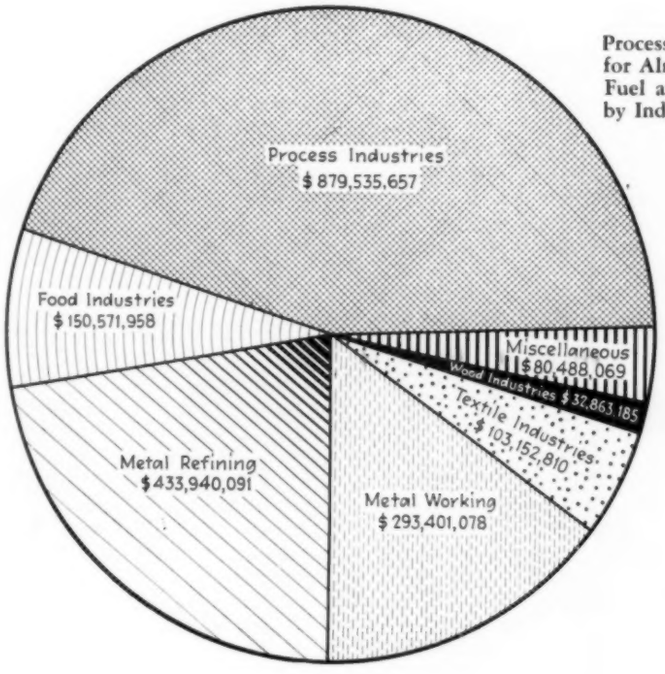




In the chart above the item for "other products" covers refining losses and changes in stocks of oil in process from year to year. Percentages shown for the four major classes of products are the proportions by volume related to the total crude oil used. Data furnished by G. R. Hopkins, U. S. Bureau of Mines, for 1916-30. Other statistics from Census of Manufactures.

By R. S. McBRIDE

In addition to serving as editorial representative in Washington for *Chem. & Met.* and *Food Industries*, Mr. McBride is consulting editor of the *American Gas Journal* and consulting chemical engineer for a number of industries. Prior to 1920 he was in charge of the gas engineering and gas chemical sections of the U. S. Bureau of Standards



Process Industries Paid for Almost Half of the Fuel and Energy Used by Industry in 1929

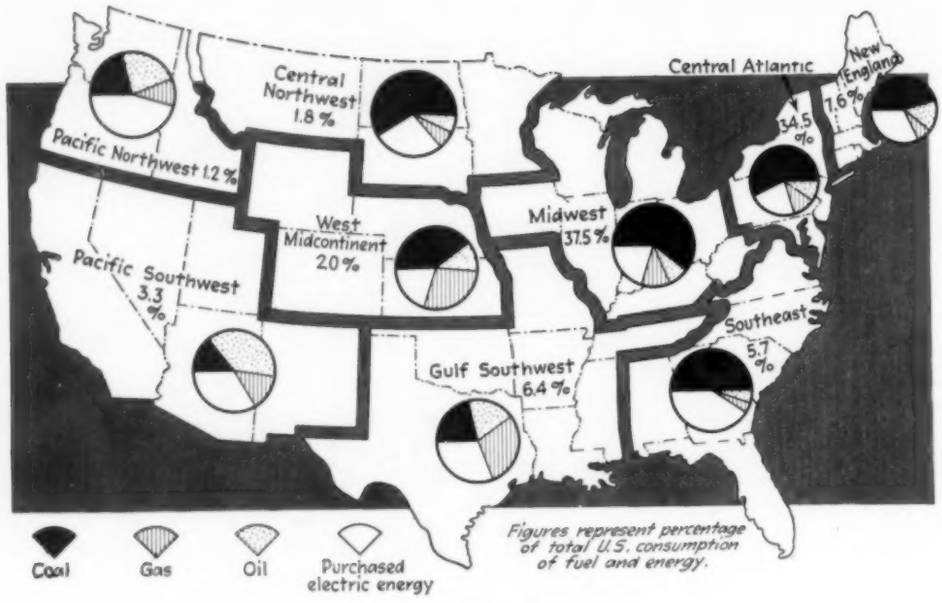
cases the working conditions established for employees in the factory indicate clearly the advantages of certain fuels over others.

COAL, the most abundant and the cheapest fuel supply, still is usually the most economical for large central stations and for the corresponding types of process-industry power plants. Used there in powdered form, it almost invariably embodies the greatest economy. The downward trend in annual consumption of coal by the country as a whole shows, however, the significant progress made both in more efficient use of coal and by other fuels in the inter-energy competition. Outstanding factors which have produced this result include:

1. Tremendous expansion of available supply and an excess of production over normal consumption requirements of crude petroleum.
2. Disclosure of tremendous new natural-gas reserves and their development by long-distance pipe lines for both industrial and municipal public-utility supply.
3. Constant trend toward lower fuel cost relative to labor cost, giving to oil and coal a relative utilization advantage because of less labor per unit in handling and burning.

Anthracite, fuel briquets, and coke have continued to be the minor solid fuels. There has been a decided downward trend in anthracite production and consumption during several recent years, as evidenced in the accompanying charts. The development of coke has in some measure reacted unfavorably on anthracite requirements, especially for gas making and in the field of household fuel. Usually, however, none of these minor solid fuels offers compensating attractions for its greater unit price, except in such special applications as foundries, blast furnaces, and water-gas plants.

OIL, which even in the years of the World War accounted for only about 10 per cent of the energy supply of America, now furnishes well over 25 per cent of the total supply, measured in heat units. Because of the greater thermal efficiency customary in its use than is common with coal, it contributes an even higher percentage toward total useful service of fuels. There is every evidence that the trend toward still higher oil utilization, especially in process industries, will continue. This increase is limited mainly by the development of fuel gases, especially natural gas and the byproducts of petroleum and natural-gasoline refining. This is an amazing situation when one recalls that less than 15 years ago responsible



Where Fuels and Purchased Electric Energy Are Used by American Industry

estimates indicated that within 10 or 12 years the available reserves of domestic petroleum as then known were likely to be largely exhausted. Today the proved reserves are many times greater. This increase resulted not only from exploration of new areas underlaid with petroleum but also from improved technology recovering a much higher percentage of petroleum from the earth than was possible only a decade ago.

Processing of petroleum into its many products has also advanced, largely as an achievement of refined chemical-engineering industry. Today through hydrogenation it is entirely practicable to secure more than 100 gal. of gasoline from 100 gal. of crude petroleum treated; practical operating percentages are from 60 to 85 per cent. This is in striking contrast with recoveries of only 20 to 25 per cent with some cracking processes in use 12 to 15 years ago. Without hydrogenation at least 40 to 55 per cent and often as high as 60 per cent of the crude is recovered as gasoline. The recoveries are, of course, in all cases determined by economic limitations set by relative market prices of crude and of products, rather than by any technologic limitations or inability to make a higher yield.

Utilization of petroleum products as a source of process energy usually is limited to the burning of gas oil or fuel oil. Comparatively few applications have yet been made of internal combustion engines either of the automotive or diesel types. Hence the selection and purchase of liquid fuel generally relates to that wide variety of petroleum products heavier than kerosene. Of these products, the process industries use about 60 per cent of the total domestic supply. Included are the requirements of manufacturing industry, oils for gas making, and utilization of fuel oil by the petroleum-refining industry itself. The distribution of the gas oil and fuel oil production for 1926 and 1930 is shown on page 189.

In a choice between the types of oils available, the purchaser usually can regard utilization efficiency in proportion to the heat content of an oil. Hence the poundage per gallon becomes an important consideration in price comparisons, although the heating value per pound does not vary widely over the range of oils considered.

Interchangeability of oil and gas as furnace fuels is a consideration of material importance both in selection of fuel and in choice of heating equipment. Especially in areas where surplus supplies of natural gas are now available, it is important that the industries take advantage of these supplies, but if possible without committing themselves to equipment that will compel either continued purchase of gas at subsequently higher rates or its entire replacement. Use of "conversion" burners permitting interchange between oil and gas accomplishes this purpose, usually without sacrifice of more than 1 or 2 per cent in the thermal efficiency of utilization of either fuel.

GAS AND ELECTRICAL energy are available both by purchase from public-utility enterprises and by generation in the industry's own plants. With the development of modern industrial-rate schedules for utility services it is often advantageous to buy rather than to generate where moderate quantities of gas or power are needed. Of course, outstanding exceptions to this generalization are found in plants which have both process-steam and electrical-power requirements, especially when they are so nearly balanced that bleeder-turbine drive for electric generators can be used to step down practically all the high-pressure steam to the level at which it serves processing purposes. A more complete discussion of generated vs. purchased power in a later part of this issue makes further dilation unnecessary here.

Formerly, generation of producer gas in the industrial plant was widely practiced. It is still most economical in certain plant locations, particularly where abundant supplies of city gas are not available under favorable industrial-rate schedules. The modern gas producer or blue-gas generator serves such plants admirably, utilizing anthracite, bituminous coal, or coke. However, such an installation is not usually the most economical if a plant is convenient to a large natural- or manufactured-gas supply. Public-utility enterprises are generally able to furnish gas on rate schedules that should make the cost delivered at the industrial plant favorable by comparison in all but the largest quantities.

In comparison between purchased and generated gas it is necessary, of course, to take account of numerous factors. Among those which favor a purchasing policy are the freedom from dirty gas-generating operations in the plant; requirements of very little new capital for connecting with a public-utility system, as contrasted with that for installation of generating facilities; the opportunity to pay for fuel used some time after the end of the month of use; elimination of the necessity for such stocking of fuel as is required when coal or coke is used in the plant generator.

ability to modify either upward or downward the rate of use of gas on a basis generally wider for purchased supplies than can be warranted for plant-generated gas.

PURCHASE of gas for industrial usage makes it important to schedule heating operations in order to maintain a minimum peak of demand. In some cases such scheduling is of vital importance if the management is to obtain the most favorable rates from the public utility serving it. Industrial rate schedules usually provide for the irregularity of demands by imposing either a customer charge and/or a demand charge which are constant regardless of quantity of fuel used. Under such a rate schedule the minimum cost for fuel can be obtained only by distributing the demand as uniformly as possible, both throughout a single working day and throughout the days of the week and the month. In a few cases, such rate schedules will warrant important heating operations on evening or night shifts or over week-ends.

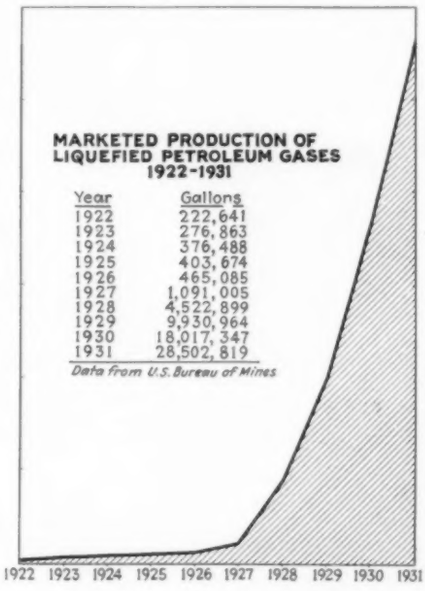
In a few cases the rate schedules offered by utility companies give much lower rates per thousand cubic feet of gas used *exclusively* at off-peak periods. Still more commonly it is an advantage to arrange for the use of gas only during certain seasons of the year. In some plants gas can be made available at very low rates for the summer season. In Chicago, for example, gas is supplied at as low as 20 cents per thousand cubic feet for summer water-heating installations, a rate less than half that which would be paid for year-round service in the same quantity. Both the utility company which has the surplus seasonally available and the user industry may find great advantage in such seasonal gas contracts. In some instances they can be very satisfactorily used for replacement of oil or coal during the period from April to October by merely introducing properly designed "conversion" gas burners into furnaces fired with other fuels at other seasons. The advantages of such substitution, of course, include those of greater flexibility in furnace or boiler control, a reduction of boiler room labor, and a tendency toward increased cleanliness and comfort for employees throughout the plant. Especially in areas where large quantities of natural gas are being used for house heating, these summer rate schedules are becoming increasingly available to process industries.

BYPRODUCT GASES are today available from the coke industry, from petroleum refining, and from the "stabilization" of natural gasoline. The total gaseous fuel so available far exceeds the supply of all manufactured gas of other types marketed through public utilities or otherwise. Supplies of propane, butane, or their mixtures are being marketed industrially at the present time by about a dozen producer

MARKETED PRODUCTION OF LIQUEFIED PETROLEUM GASES 1922-1931

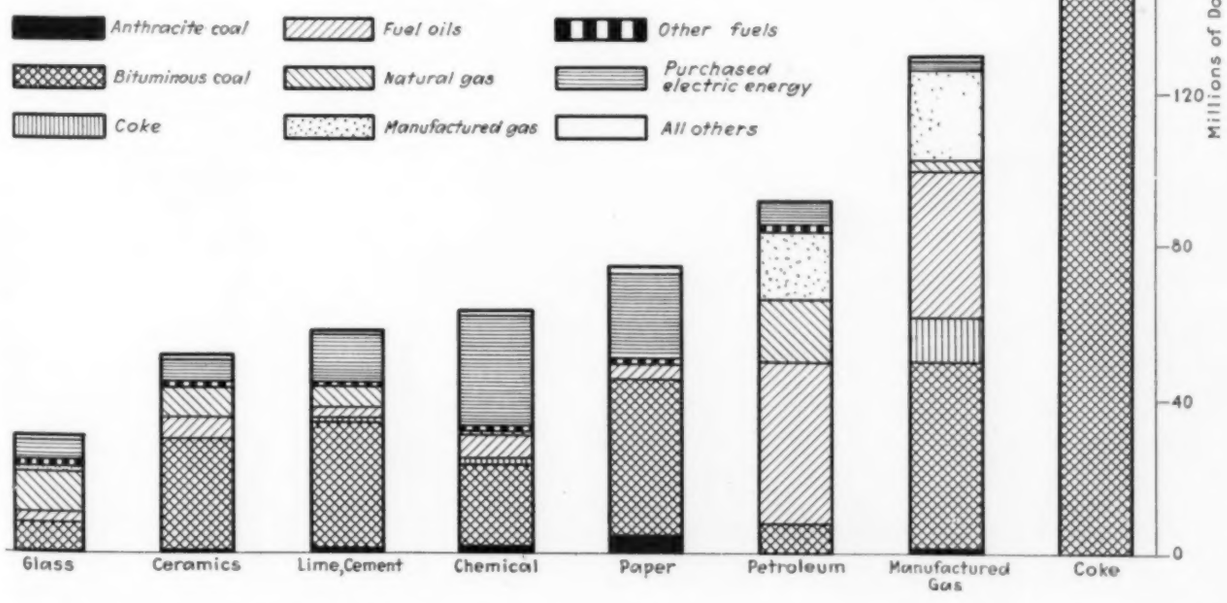
Year	Gallons
1922	222,641
1923	276,863
1924	376,488
1925	403,674
1926	465,085
1927	1,091,005
1928	4,522,899
1929	9,930,964
1930	18,017,347
1931	28,502,819

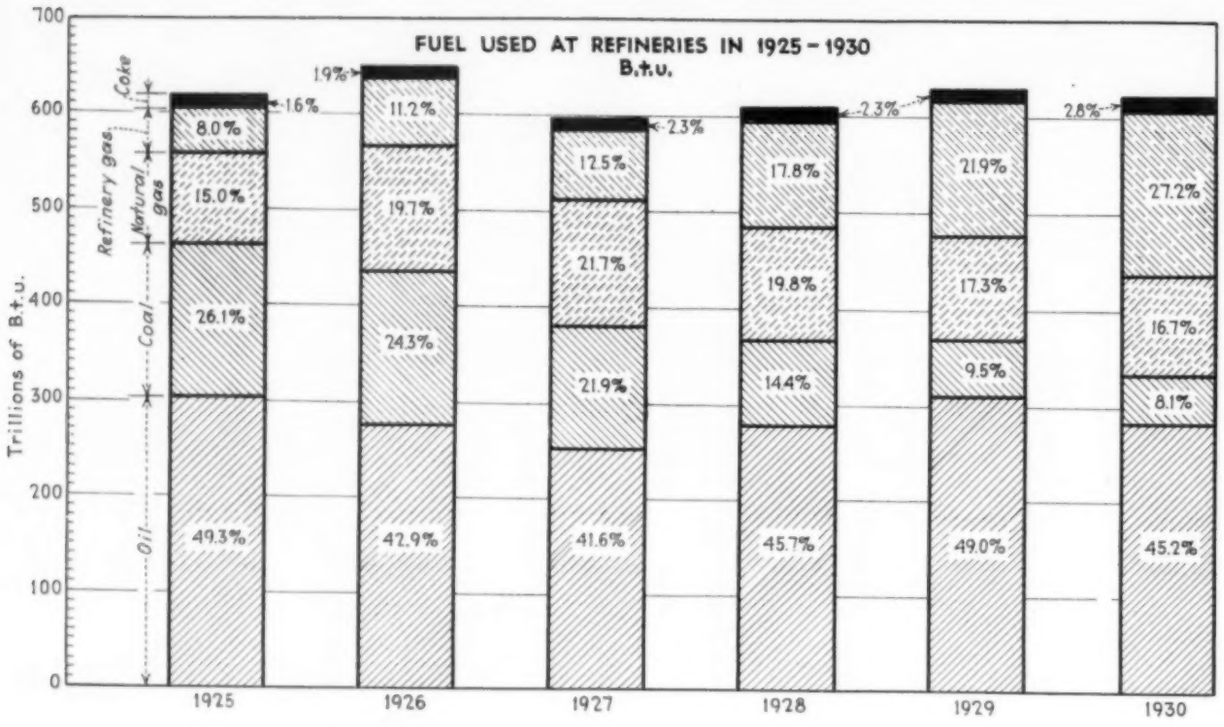
Data from U.S. Bureau of Mines



"Consumption of Fuel and Electric Energy in Manufacturing Industries in 1929," published by the U. S. Census of Manufactures, March, 1932, is authority for the data shown below. The group "All Others" refers to miscellaneous requirements too small to be presented graphically. Detailed figures are given on page 190

LARGE USERS OF FUEL AND ENERGY AMONG PROCESS INDUSTRIES





Use of Gaseous Fuels in Petroleum Refineries Increased From 23 Per Cent in 1925 to 43.9 Per Cent in 1930
(Data supplied by G. R. Hopkins, U. S. Bureau of Mines)

groups. In 1931, the total supply of these fuels was in excess of 28,500,000 gal., more than 7,000,000 gal. being used industrially and about 6,000,000 for small-town gas manufacture or for enriching city gas in other larger communities. If the present trend of supply of these byproducts of petroleum and natural gas continues it may be expected that they will become a more important factor in the gas supply of the United States than even the total quantity of byproduct coke-oven gas now is. The quantities already available are actually in excess of the coke-oven gas available, but utilization has not yet progressed to a full application of these oil and gasoline byproduct supplies.

Utilization of gaseous fuel for process heating does not *require* equipment superior to that used for oil or powdered coal. However, a somewhat greater cost per million heat units often *warrants* a refinement of utilization equipment that could not be justified with a relatively low-cost fuel. Even though such refinement in equipment may, and usually does, require some new investment, the over-all cost, including the benefit in superior product and economy of labor due to controlability, many times justifies both capital expenditure and somewhat greater current fuel bills.

COMPARISON between any two gaseous fuels can safely be made, in most instances, purely on the basis of the relative cost per million heat units, or, reciprocally, the number of heat units available for a dollar. There are, however, two exceptions to this general rule which should be noted, cases in which the percentage of inerts included must be taken into account. It is not possible to do as much work with a million heat units in the form of producer gas of which 80 per cent is in nitrogen or carbon dioxide as with a million heat units of a fuel of higher heat concentration. In a few instances of manufactured gas with very high inert content, nitrogen and carbon dioxide, a similar but much smaller factor of disadvantage enters. In all other cases, save where equipment is run on extremely high thermal efficiencies, the B.t.u. per cubic foot is a direct measure of industrial heating worth.

The heating value of industrial gases is expressed in terms of total or gross B.t.u. per cubic foot. In a very few instances, where equipment can be run with condensation of the moisture from the products of combustion, it is possible to realize more than 80 to 85 per cent of the total heat. Usually the last 12 to 15 per cent unavoidably escapes with the products of combustion in the form of heat in uncondensed water formed during combustion. Deducting this heat of condensation from the total heating value, one obtains the net, sometimes called "lower," heating value. For extreme refinement of comparison it is occasionally important to consider this characteristic of a fuel. Rarely, however, does the loss due to failure to condense the water formed by combustion become a practical considera-

Water Power Capacity in U. S., 1921-1932

(Data from U. S. Geological Survey)

Date	Horsepower	Per Cent Increase
1921 (November)	7,926,958	....
1924 (March)	9,086,958	14.6*
1925 (March)	10,037,655	10.5
1926 (Jan. 1)	11,176,596	11.3†
1927 (Jan. 1)	11,720,983	4.9
1928 (Jan. 1)	12,296,000	4.9
1929 (Jan. 1)	13,571,530	10.4
1930 (Jan. 1)	13,807,778	1.7
1931 (Jan. 1)	14,884,667	7.2
1932 (Jan. 1)	15,562,805	4.3

*About 2.3 years. †About 0.8 year.

Distribution of Water Power Capacity in United States, 1921-1932

(Data from U. S. Geological Survey)

Division	Percentage of Total in United States									
	1921	1924	1925	1926	1927	1928	1929	1930	1931	1932
United States	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
New England	16.5	15.3	14.0	13.3	13.1	12.7	12.2	11.9	12.7	12.4
Middle Atlantic	18.7	19.1	19.4	17.9	17.5	16.9	15.6	15.3	14.9	14.8
East North Central	9.3	9.1	8.8	8.8	8.6	8.4	8.0	7.8	7.3	7.1
West North Central	5.6	5.1	5.1	4.7	4.6	4.4	4.1	4.0	3.8	4.9
South Atlantic	13.6	14.3	15.8	15.2	15.7	16.0	19.1	19.2	19.6	19.1
East South Central	3.1	3.8	4.0	6.7	7.4	7.9	8.2	8.4	9.2	8.8
West South Central	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.3	0.9
Mountain	10.4	9.7	9.3	8.8	8.8	9.1	8.4	8.6	8.2	7.8
Pacific	22.6	23.5	23.3	24.5	24.0	24.3	24.0	24.4	24.0	24.2

National Distribution of Gas Oil and Fuel Oil, 1926-1930

(Figures in barrels of 42 gal. each)

Uses	1926	1930
Railroads	72,000,000	68,000,000
Steamships	79,000,000	94,000,000
Gas and electric plants	34,000,000	28,000,000
Smelters and mines	9,000,000	6,000,000
Iron and steel products	16,000,000	15,000,000
Chemicals and allied ind.*	.....	4,000,000
Automotive industries	2,000,000	2,000,000
Textiles and their prod.*	.....	4,000,000
Paper and wood pulp*	.....	2,000,000
Logging and lumbering	3,000,000	2,000,000
Cement and lime plants	6,000,000	3,000,000
Ceramic industries	3,000,000	2,000,000
Food industries	7,000,000	7,000,000
Other manufacturing	23,000,000	12,000,000
Commercial heating	14,000,000	17,000,000
Domestic heating	3,000,000	10,000,000
U. S. Navy, Army, etc.	7,000,000	9,000,000
Used by oil companies	49,000,000	53,000,000
Miscellaneous uses	7,000,000	11,000,000
Exports and other shipments	39,000,000	36,000,000
Total distribution	373,000,000	385,000,000

*Included under "Other manufacturing" in the 1926 survey.

Note — Table does not include distribution of furnace oils for domestic heating, in following quantities: 1926, 6,000,000 bbl.; 1930, 15,537,000 bbl.

tion in fuel comparisons. Usually it is necessary to permit sufficiently high stack temperatures in order to prevent the formation of drip by this water so that the total realizable heat is less than the net heating value of even those gases containing highest percentages of free or combined hydrogen. (In calculating the net heating value, the total of *all* hydrogen contained must be taken into account.)

Most frequently the use of excessive supplies of secondary air in the combustion chamber is a more serious cause of stack loss than are any of the other considerations just referred to. The restriction of secondary air is a matter wholly within the control of the management, assuming that the equipment is not so faulty as to preclude setting of secondary-air dampers for proper restriction of its supply.

FUTURE developments in fuel utilization by the process industries unquestionably will be important factors in the technology of tomorrow. It is difficult to say to what extent the different energy sources will have a part, but an effort has been made to appraise the trends of today and use them for an estimate of tomorrow's practice. The adjoining estimate of probable energy sources in the United States for the calendar year 1940 is the result.

	Average for Years 1923 to 1927		Estimated for 1940	
	Trillions of B.t.u.	*Per Cent of Total*	*Trillions of B.t.u.*	*Per Cent of Total*
Anthracite coal	2,000	8	1,500	5
Bituminous coal	14,000	60	15,500	48
Petroleum	5,000	20	8,000	25
Natural gas	1,500	6	5,000	16
Water power	1,500	6	2,000	6
	24,000	100	32,000	100

Changes in heat application by improved equipment and by better factory control of heat processing appliances is also to be expected. The result will be to some extent a lowering of the cost of production in the output of the process industries. More important, however, will be an improvement in the quality and the uniformity of its products.

Production and Consumption of Natural Gas, 1930

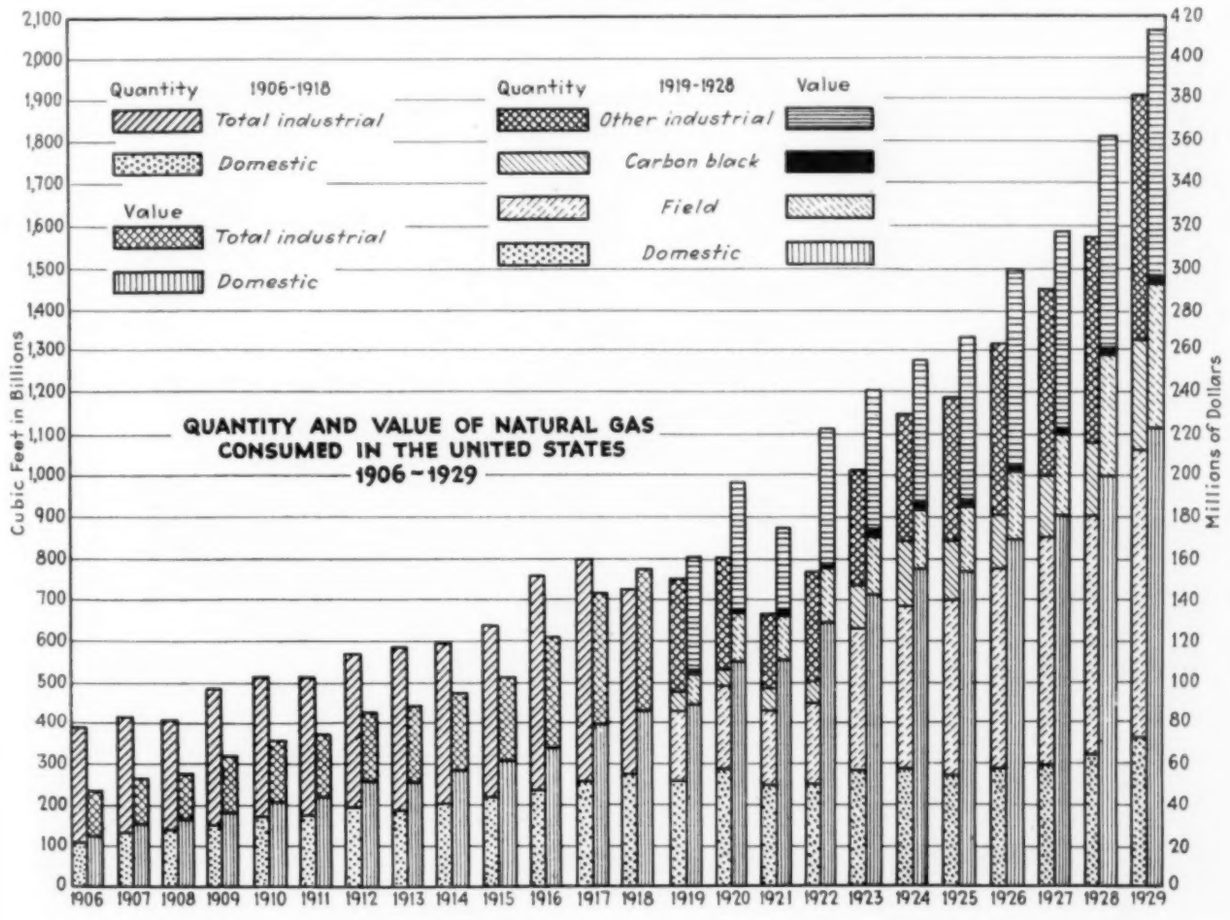
(From U. S. Bureau of Mines)

	Millions of Cu.Ft.	Value
Production	1,943,421	21.4*
Consumption:		
(a) Domestic	376,407	63.5*
(b) Field (drilling, pumping, gasoline plants, etc.)	723,165	$59,118,000
(c) Carbon black manufacture	266,625	$6,002,000
(d) Petroleum refineries	98,842	
(e) Electric power plants	120,290	
(f) Cement plants	41,256	$111,226,000
(g) Other industries	315,059	

*Average values at points of consumption in cents per M. cu.ft.

The Use of Natural Gas as an Industrial and Domestic Fuel Increased by Almost 400 Per Cent From 1906 to 1929

(Data from Mineral Resources of the United States, 1929)

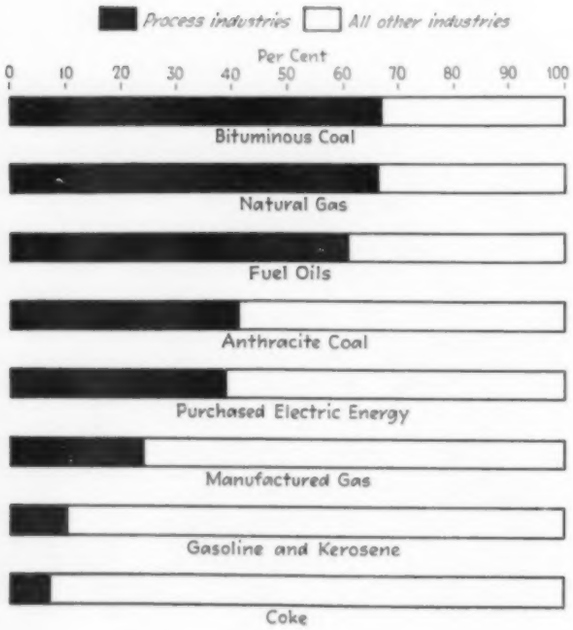


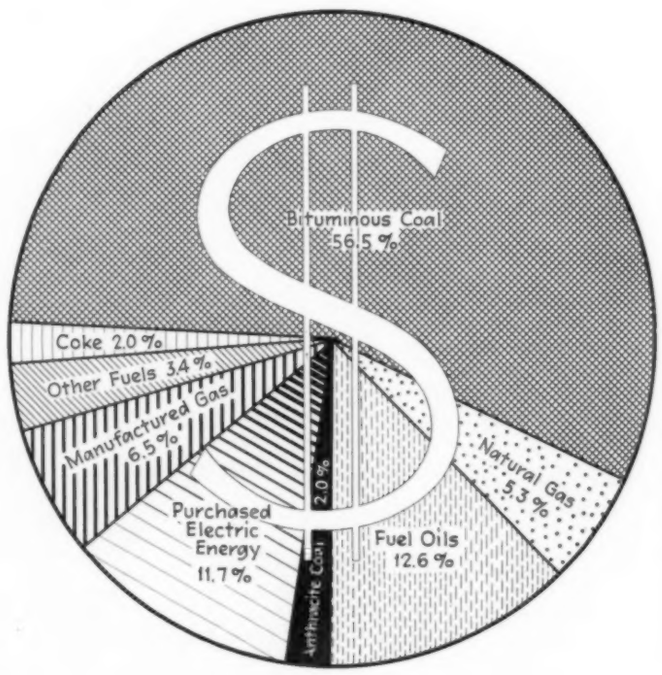
PROCESS INDUSTRY REQUIREMENTS FOR FUEL AND PURCHASED ELECTRIC ENERGY

	Total Cost of Fuel and Purchased Electric Energy (Dollars)	Coal: Anthracite (Tons, 2,240 Lb.)	Coal: Bituminous (Tons, 2,000 Lb.)	Coke (Tons, 2,000 Lb.)	Fuel Oils (Gallons)	Gasoline and Kerosene (Gallons)	Natural Gas (M.Cu.Ft.)	Manufactured Gas (M.Cu.Ft.)	Purchased Electric Energy (Kilowatt-Hours)
Chemical	62,846,802	351,899	6,520,179	200,840	211,342 505	823,806	6,523,842	960,027	6,135,092,295
Ceramics	52,732,162	176,142	8,783,593	56,882	119,640,018	1,184,143	31.667,481	355,133	437,597,331
Coke	284,764,800	15,327	82,346,921	1,747,641	6,005,857	111,588	977	117,897,150	170,027,067
Drugs	3,081,062	74,465	208,491	1,494	5,236,508	289,938	54,981	104,425	37,606,252
Explosives	1,901,919	34,646	183,206	111	16,610,914	8,210	55,161	1 295	39,109,724
Fertilizers	2,871,137	4,934	124,897	995	5,701 894	88,064	168,592	1,227	97,842,555
Glass	30,179,377	97,470	2,310,195	1,585	57,088,770	323,715	51,341,523	2 093,858	502,313,691
Glue, Gelatine	1,616,794	12,280	305,325	399	924,444	2,727	926	16,431	7,497,654
Leather	6,740,613	32,791	1,064,283	2,744	4,661,063	21,063	15,686	4,791	74,185,894
Lime, Cement	58,882,812	345,199	10,090,017	71,395	134,715,732	462,362	35,854,868	254,164	1,447,766,809
Manufactured Gas	130,997,614	196,706	10,073,075	1,445,030	923,886,596	410,898	11,220,925	91,985,663	282,464,292
Oils, Greases	9,773,118	28,277	1,086,896	3,476	29,879,353	211,111	4,378,023	17,203	267,971,957
Paints	6,860,268	82,582	538,993	47,841	16,313,175	115,934	344,028	334,224	149,610,040
Paper	75,266,601	1,135,738	9,811,522	1,290	130,244,908	65,432	12,047,519	9,515	2,816,016,927
Petroleum	92,067,503	190 754	2,597,450	.....	2,164,118,999	.....	118,652,262	88 318,120	660 625,288
Rayon	4 319,040	8,300	766,638	.....	2,694,473	107,610	753	315	152,364,940
Rubber	19,677,375	84,269	2,305,540	472	19,993,678	172,719	1 296,559	35,152	882 449,734
Soap	3,883,985	126,844	593,343	6,380	4,110,776	192,714	188,409	21,455	61 958,174
Sugar	12,137,730	445,809	1,568,490	44,208	102,440,422	53,539	8,187,411	36	17,036,317
Other Process Industries	18 934,945	402,545	2,177,634	23,181	63,346,414	241,309	3,711,834	167,489	407,360,873
Total for Process Industries	879,535,657	3,846,977	143,456,688	3,655,964	4,018,956,501	4 886,882	285,711.760	302,577,673	14,646,897,614
Total for All Industries	1,973,863,329	9,281,416	214,024,754	52,391,839	6,583,198.995	48,473,195	429,826,799	1,258,450,089	37,393,833 046
Per Cent of Total in Process Industries	43.5	41.5	67.1	7.0	61.0	10.1	66.5	24.0	39.2

Source: U. S. Census of Manufactures, 1929, "Consumption of Fuel and Electric Energy in Manufacturing Industries," Published March, 1932.

Process Industries Account for Two-Thirds of Industrial Consumption of Both Bituminous Coal and Natural Gas. Purchased Electric Energy, It Will Be Noticed, Finds a Relatively Much Smaller Consumer in the Process Industries




Bituminous Coal 56.5 %
Coke 2.0 %
Other Fuels 3.4 %
Manufactured Gas 6.5 %
Purchased Electric Energy 11.7 %
Anthracite Coal 2.0 %
Fuel Oils 12.6 %
Natural Gas 5.3 %

How the Fuel Dollar Is Divided in the Process Industries. Bituminous Coal Continues to Be the Premier Industrial Fuel, Despite Inroads of Gas and Oil

A Statement of Fundamentals

In Process Heat Application

AS WAS emphasized in earlier pages, nothing so simple as a dollars-and-cents comparison on the basis of calorific value of various heat sources can be made, either safely or with economic justification, in most process-heat applications. How many B.t.u. can be bought for a dollar is not the measure of the value of a stated fuel. Rather, what its thermal accomplishment is in any given case, in comparison with the accomplishment of a dollar's worth of competing fuel, must be the standard of value. The fuel which will make the best product most cheaply, with due consideration to desirable operating conditions, will be the one best chosen.

FUEL, after all, is only a means to an end, and the end must be the starting point in the choice of both the method and the means of supplying process heat. Theoretically, B.t.u. for B.t.u., all fuels are substantially equivalent. Electricity, considered as a heat source, need heat no excess air, no combustion gases that must be sent up the stack. Producer gas, high in inerts, wastes more heat to the stack than does natural gas. But the differences in heat available come far from equalizing differences in cost per unit. And provided that one is prepared to spend as much as may be necessary in supplying the proper equipment, there need be no great differences in heat available.

THIS matter of equipment is really the heart of the whole question of fuel relations. Fuel efficiency comparisons can rightfully be made only in equipment that is comparable. Yet, how often will this be done? Expensive fuels "justify" expensive and highly efficient equipment—cheap fuels, cheap and relatively inefficient equipment. And yet, it is a demonstrable fact that coal, the cheapest fuel, can be used as efficiently as electricity, the most expensive, always provided that the equipment required is the equipment chosen. This does not mean that no more B.t.u. will be required in using coal, for this is not the case; nor does it mean that coal will always permit a sufficiently elevated temperature to be reached. But it does mean that, in the vast majority of cases, coal can make a proper product.

WHY is it, then, that the more expensive fuels can and should compete on an economically justifiable basis? Simply, for the reason that the cost of fuel is not the only cost—frequently it is but a small part of the cost—of process heating. Fixed charges on equipment, labor costs, even intangibles such as convenience, cleanliness, morale, good operating conditions, all these are part of the cost that must be borne. When the equipment is scanted, spoilage and lowering of the general level of product quality must be counted as costs that are directly chargeable to heating. Hence, heat source and equipment are only two variables in an equation, the resultant of which is product.

EQUIPMENT thus becomes the center of a ring of interrelated factors, all of which influence its design. If cheap fuel and cheap equipment can be made to produce the desired results, well and good. Again, cheap fuel and expensive equipment, or expensive fuel and cheaper equipment, may be found the economic solution. Only careful analysis can show which combination must be chosen. But in any event, some improvement in fuel, in equipment, in control or thermal effectiveness, will generally lead to a practical compromise with the ideal.

LET'S CONSIDER STEAM—

A quick glimpse into the peculiarities and potentialities of the steam B.t.u., its generation and its utilization

By THEODORE R. OLIVE

Assistant Editor, Chem. & Met.

BY WAY OF introducing the articles on steam and power that follow, the present article will attempt to recall some of the things that power engineers must remember, and chemical engineers may find confusing and easily forgotten. What is steam? How is it produced? What can be done with it? And how can it be used most efficiently? The answers to some of these questions are not always simple; for instance, the first. A complete definition of any particular pound of steam must specify certain of its characteristics which will automatically fix all its other characteristics.

A pound of water enters a boiler. What happens to it? Assume a system consisting of a furnace, a boiler and feed-water pump, and two separate pipes for removing the steam, either of which can be used. One pipe goes directly from the boiler drum to a spring-loaded valve, capable of holding any desired pressure on the drum. The other pipe is split into several branches to increase its surface and these branches are installed within the furnace. This is the superheater. The branches then join and the single pipe discharges through the same spring-loaded valve.

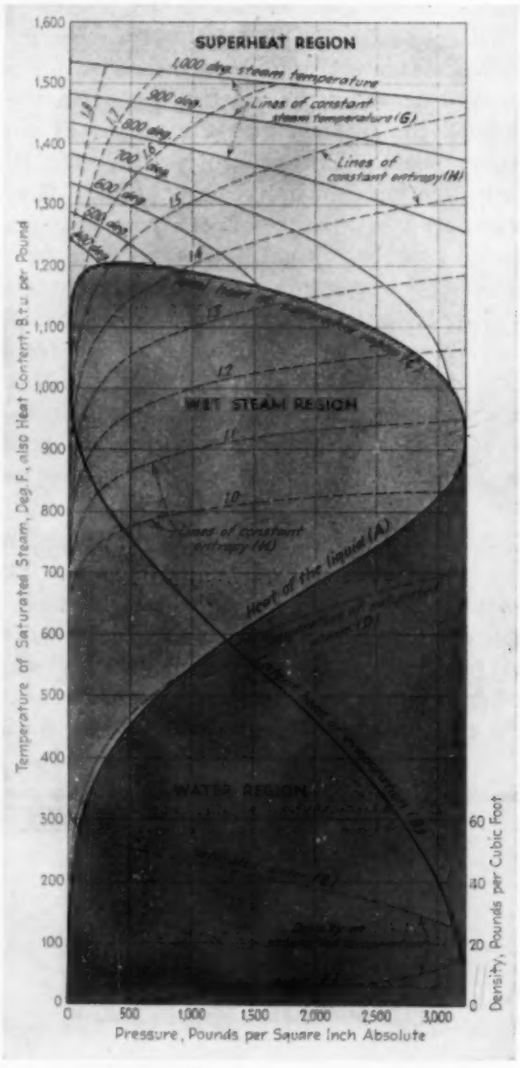
The clue to what happens when our pound of water enters the boiler is found in Fig. 1* in which the characteristics of steam are plotted on the total heat-pressure plane, a type of diagram which is not very practical for actual use, but is better suited to illustration than the more usable Mollier diagram. Every point on the diagram represents some condition of steam or water. In general, there are three areas, as are shown by the various shadings. Every point below Curve *A* represents water. Points between Curves *A* and *C* are wet steam, and above Curve *C*, superheated steam.

Suppose our pound of water has a temperature of 32 deg. F. when it enters the boiler. Boiler pressure is set at 100 lb. per square inch absolute on the spring-loaded valve. Then, as heat is absorbed, the temperature of this pound increases until it reaches 328 deg. (Curve *D*), and in so doing it absorbs 298 B.t.u. (Curve *A*). Now that it is at boiler temperature, further heat absorption is used entirely for evaporation and no further temperature rise can occur. For each B.t.u. now absorbed there is an increment of evaporation until when 888 additional heat units (Curve *B*) have entered the water, it has all become dry, saturated steam with a total heat content of 1,187 B.t.u. (Curve *C*). As long as this steam remains in contact with unevaporated water in the boiler, no further heat can be added to it.

As our pound of steam evaporates, and as it grows enormously in volume, from 0.017 to 4.451 cu.ft. (reciprocals of Curves *E* and *F*), it pushes itself out through the discharge pipe and spring-loaded valve and leaves the system. Suppose, however, that it goes through the furnace by way of the superheater. Here it absorbs additional heat units and increases in temperature and volume. But the pressure is fixed so that the characteristics of this superheated steam can be predicted from the chart. Its actual heat absorption, of course, will depend on design and operating factors, but, for the sake of argument, if the steam absorbs 91 more B.t.u., its temperature will rise to 500 deg. A further absorption of 255 B.t.u. will increase the temperature to 1,000 deg. (Curves *G*). Whatever the pressure, all superheated steam of a certain temperature will lie along the corresponding steam-temperature curve, which immediately shows its heat content. Similarly, all saturated steam, regardless of its pressure, will lie along Curve *C*, its temperature along Curve *D*, and all wet steam at the proportional distance between Curves *A* and *C*. This proportion is called the "quality"; *i.e.*, 100 lb. steam of 90 per cent quality (10 per cent moisture) will have a total heat of 298 (Curve *A*) plus 0.9 × 888 (Curve *B*) equals 1,097 B.t.u.

If instead of 100 lb. boiler pressure we had chosen 425 lb., we should have noted a peculiar fact: that is, that saturated steam at this pressure contains more heat per pound than steam at any other pressure. While it would seem logical that higher pressure would store up more heat, this is not the case. Steam at the critical pressure (3,226 lb.) actually contains 148 B.t.u. per pound less than steam at 32 deg. F. Whether this is due to a varying state of aggregation of the water

Fig. 1—Properties of Steam as Shown on the Total Heat-Pressure Plane



*Prepared from the Keenan Steam Tables and Mollier Diagram, A.S.M.E., 1930.

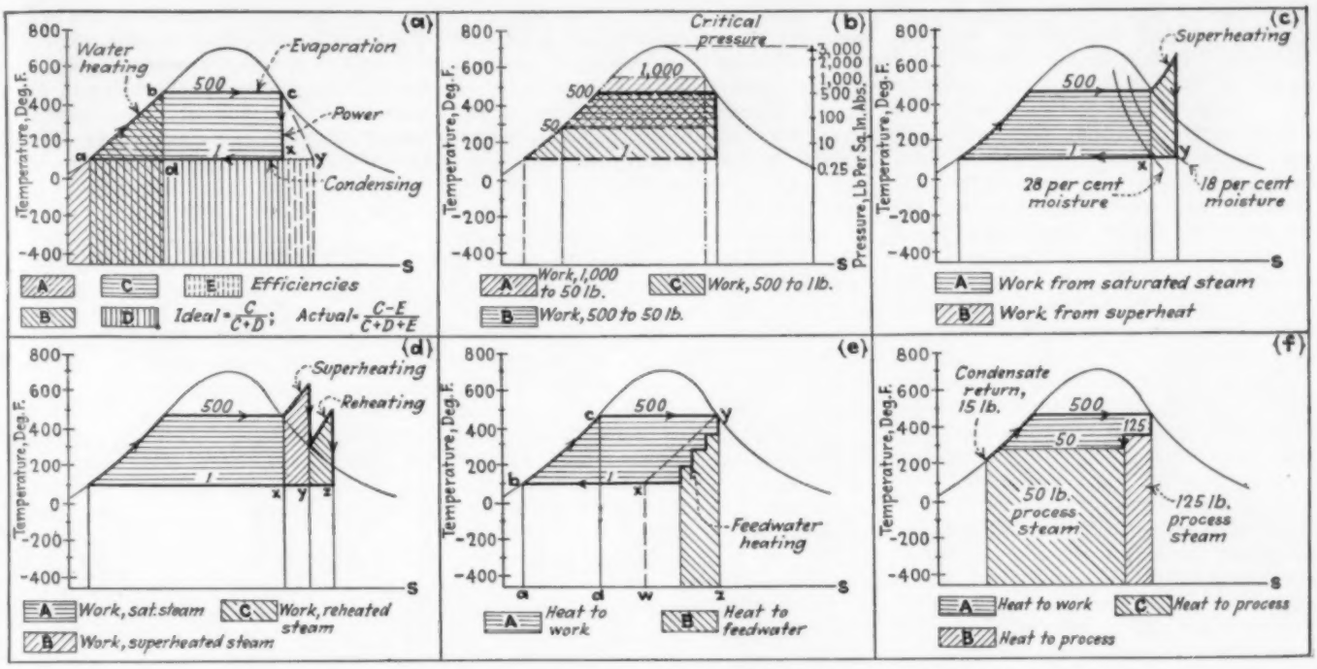


Fig. 2—Steam Cycles That Illustrate Power Efficiency and the Various Methods for Using Steam in the Production of Power and Process Heat

molecules or to a requirement for proportionately less energy in vaporizing as the steam volume decreases, is a debatable question. Perhaps both conditions coexist.

There is one further characteristic of steam which is a measure of its "work potential." This is known as "entropy," the value of which is fixed for steam of every definite condition. According to the second law of thermodynamics, any change which takes place of itself in a system results in an *increase* of entropy; *i.e.*, in a *decrease* in the ability of the system to do work. Any expansion of steam, therefore, increases its entropy—except in an ideal engine. Steam passing through an orifice or reducing valve from a higher to a lower pressure does no external work and loses none of its heat content. But the entropy of this steam increases during the expansion.

What happens to steam when it expands under any given set of conditions can readily be seen by following the chart horizontally to the left from the initial to the final condition. The final steam contains as much heat as it did before the expansion, but it can do less work. Also, its temperature or quality will have changed in most cases. Such expansion represents one limit in the possible expansion range. That is, it is impossible for the steam to do less than no work. Expansion down one of the lines of constant entropy (Curves *H*) represents the other limit and here the steam does as much work as possible. Adiabatic expansion, such as would be achieved in an ideal engine, follows an entropy line and therefore represents the maximum work production that is possible between any two pressures.

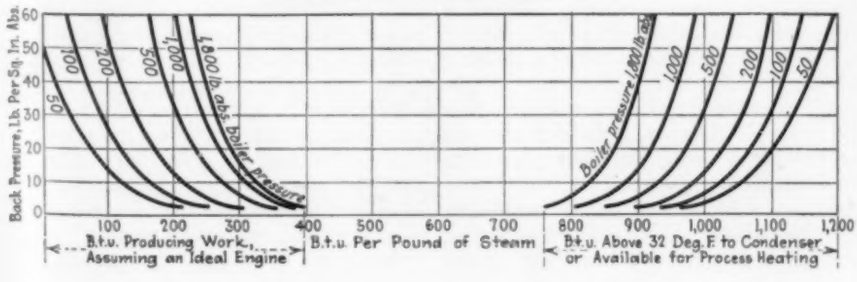
Steam can accomplish two useful things: it can give up its heat to a process, and it can do work in a suitable engine. Since its heat content is measured above 32 deg. F., if it is used to melt ice, it can give up every B.t.u. it contains. Not all its heat, nor all of any form of heat, can be converted entirely into work. Yet work can be transformed completely into heat—and it always is—for eventually every unit of work performed in the universe becomes 3,415 B.t.u. of heat for each kilowatt-hour expended.

When steam or any other heated fluid is put to work in an engine, the quantity of work evolved depends on the temperature (or pressure) limits between which it works; that is, the entering temperature and the temperature at which it is rejected to the condenser. And these temperatures, unfortunately, must be measured on the absolute scale, where 32 deg. F. becomes 492 deg. Rankine and 1,000 deg. F. becomes 1,460 deg. Rankine. Where T_1 is the entering temperature (absolute), and T_2 the rejection temperature, $(T_1 - T_2)/T_1$ is the maximum efficiency of heat-to-work utilization that can ever be attained. This is the Carnot efficiency, which is the limit even for an ideal heat engine. In any actual engine, the efficiency will be considerably less.

Although a turbine will extract only 3,900 to 4,000 B.t.u. in producing a kilowatt-hour (worth 3,415 B.t.u.), it will reject twice as many—or more than twice as many—B.t.u. to the condenser. In the best steam practice today, 13,000 B.t.u. at the turbine throttle will produce but one kilowatt-hour. How can this be bettered? In two ways: one, use a binary-vapor cycle, a subject which is covered in another article; and the other, use the rejected heat as such—use it for heating and charge the turbine and its "byproduct power" only for the heat that is actually removed from the steam. Including boiler losses, about ½ lb. of coal will make 1 kw.-hr. of byproduct power. Whether it will pay to do this will depend on the heat-power balance of the plant and on other factors that are covered in two later articles.

The six charts of Fig. 2 illustrate some of the peculiarities and some of the potentialities of steam as it is used for power. Strictly speaking, the last two charts consist of several charts

Fig. 3—B.t.u. Available for Power and Rejected to Condenser or Process at Various Boiler and Back Pressures



superimposed and consequently do not give an entirely true picture of what happens. However, for all practical purposes, they will serve to illustrate the context. All of them are plotted on the temperature-entropy plane on which *area* represents *heat change—i.e.*, absolute temperature, averaged during an interval, times change in entropy during the interval, equals heat units added or removed during the interval. The curved line on each chart is the familiar "steam dome," the left branch of which is the liquid curve; the right, the saturation curve (Curves *A* and *C*, Fig. 1). Points to the left of the dome represent water below the saturation temperature; under the dome, wet steam; to the right, superheated steam. Horizontal lines are constant pressure (or temperature), and vertical lines, constant entropy.

Chart *a* gives the ideal steam (or Rankine) cycle (*abcxa*) in comparison with the more efficient Carnot cycle (*bcxdb*). The total area under each line represents the number of B.t.u. that were put into, or removed from, a pound of water or steam in changing its condition from that at one end of the line to that at the other. Water with a B.t.u. content equal to area *A* (chart *a*) goes into the boiler at *a*. Heat equal to area *B* is added in compressing and heating the water from 1 lb. absolute pressure and 102 deg. to 500 lb. absolute pressure and 467 deg. in the boiler. Additional heat $(C + D - B)$ is put in during evaporation. If then the turbine expansion back to 1 lb. pressure were ideal (adiabatic), work equal to area *C* would be extracted. Condensation in the condenser then accounts for the rest of the heat (area *D*), so that this ideal, or Rankine, efficiency is $C/(C + D)$. Actually, turbine inefficiency (drag, eddies, etc.) causes the expansion to proceed to some such point as *y* instead of *x* and work equal to area *E* is subtracted from that which an ideal turbine would have produced. Hence, the efficiency of an actual turbine will be $(C - E)/(C + D + E)$.

Pressure Limits Important

Chart *b* shows clearly the effect of pressure limits on engine operation. If we start with an expansion between 500 and 50 lb. and wish to increase the work available (area *B*), it is obvious that increasing the top pressure to 1,000 lb. (area *A*) yields nowhere near as much additional work as would be gained by decreasing the condenser pressure from 50 to 1 lb. (area *C*). The desirability of the least possible back pressure (condenser or process steam pressure) is made even more emphatic by Fig. 3, which shows the large discrepancy between the heat used for work in an ideal engine and that rejected to the condenser (or process) for various boiler and back pressures.

If an actual engine were to be operated on dry, saturated steam, expansion into the wet-steam area (see Fig. 1) might cause trouble. Although the moisture after expansion will be less plentiful than is indicated by point *x* (28 per cent moisture) in chart *c* of Fig. 2 (because actual engines cannot give true adiabatic expansion), nevertheless, excessive moisture erodes turbine blades and introduces drag. Hence, superheat is employed as in chart *c* to reduce condensation in the turbine. With adiabatic expansion to point *y* (moisture 18 per cent), the situation would be improved. But as top pressures increase, a preliminary superheating becomes insufficient. A temperature of 750 deg. F. is now considered the practical limiting steam temperature. To avoid excessive moisture and keep within this temperature limit, modern high-pressure turbines reheat the steam as in chart *d*, preventing excessive condensation such as would occur at points *x* or *y* with no superheat or preliminary superheating only. At the same time, the turbine does more work, as is shown by areas *B* and *C*.

In the ideal of ideal turbines, the only heat that would be extracted from the operating fluid, before it was sent back to the boiler for re-evaporation, would be the latent heat. If this could be done, the Carnot efficiency would be obtained, disregarding the turbine losses represented by area *E* on chart *a*. This ideal is being approached in modern condensing practice through the use of what is called the "regenerative cycle." If steam were bled from the turbine at an infinite number of points and used to heat the return condensate countercurrently, in an infinite number of heaters, then heat equal to the area (*wxyzw*) in chart *e* would be returned to the boiler in the feed water. But this is substantially equal to the area (*abcda*), that is, the area *B* on chart *a*—or equal to the heat of the liquid. The work area (*bcyxb*) would then be equal to the Carnot area (*dbcxd*, chart *a*). Practically, the result is approximated at reasonable cost with the use of three or four bleeder heaters, returning to the feed water the heat in area *B*, chart *e*.

Finally, there is one further important boiler cycle, which for process men is the outstanding member of the group. This is the process steam-power cycle of chart *f*, in which the turbine acts substantially as a reducing valve, but with two notable differences. Steam extracted from the turbine will have less superheat or more moisture, whereas steam from a reducing valve, at ordinary operating pressures, will have slightly increased superheat. But more important, the turbine improves on the reducing valve in this detail: at little additional fuel cost, only 5 to 10 per cent, the process steam can be generated at a higher pressure than is needed for process, put through a turbine, produce an equivalent quantity of electrical energy, and still be available for process use. Just what quantity of electricity can be generated per pound of steam depends principally on the pressure limits employed in the turbine, although it is also necessary to consider the turbine efficiency. Turbines of less than 1,000 kw. capacity have efficiencies of 40 to 65 per cent. Over 1,000-kw., efficiencies range from 50 to 85 per cent with 70 per cent a fair average for use in preliminary estimates.

Preliminary Steam Calculations

Although it was developed for an ideal engine, Fig. 3 can be used in calculating byproduct power, simply by modifying the result with the turbine efficiency. For example, each pound of 500-lb. steam expanding to 50 lb. back pressure makes 174 B.t.u. available for power, with 1,030 B.t.u. above 32 deg. F. left over for process. But, with turbine efficiency of 70 per cent, there are $0.7 \times 174 = 122$ B.t.u. removed by the turbine, leaving theoretically $1,030 + 174 - 122 = 1,082$ B.t.u. for process. However, it was mentioned previously that a turbine extracts from the steam 3,900 to 4,000 B.t.u. per kilowatt-hour. The difference, $4,000 - 3,415 = 585$ B.t.u., represents external losses—principally leaks and radiation. The 30 per cent of available heat which the turbine does not employ usefully returns to the exhaust steam. Hence, for each kilowatt-hour produced in the example cited above, $3,415/122 = 28$ lb. of steam must be supplied, and with each of these 28 lb., $1,082 - 585/28 = 1,061$ B.t.u. will be available for process and 21 B.t.u. lost from the turbine. An even simpler method for calculating these relations, rougher but perhaps equally good for practical purposes, is simply to add 4 lb. more steam to the process requirement for each kilowatt-hour to be generated.

Very frequently more than one process-steam pressure is needed, in which case the turbine can be bled at one or several points as in chart *f*. Even the bled steam does work before it is extracted and produces a substantial quantity of power. The remainder exhausts to process, so that the total power, area *A*, is not much less than it would have been without the extraction. And although the steam which is extracted at 125 lb. (area *B*) has only a little more heat in it than it would have had at 50 lb. extraction, its temperature is considerably higher—344 deg. as compared with 281 deg.—and its heat is available for higher temperature operation than the exhaust heat, area *C*.

The foregoing may occasionally depart from strictest thermodynamic interpretation, as in the case of the last two charts of Fig. 2. But if it has made these conceptions somewhat clearer it will have accomplished its purpose. The chemical engineer will rarely need the experience that will fit him to design a power plant. There is, however, no reason why he should not have a good, fundamental grasp of power and steam production.

GENERATING AND UTILIZING POWER IN INDUSTRY

By W. S. JOHNSTON
Mechanical Engineer
Pottsville, Pa.

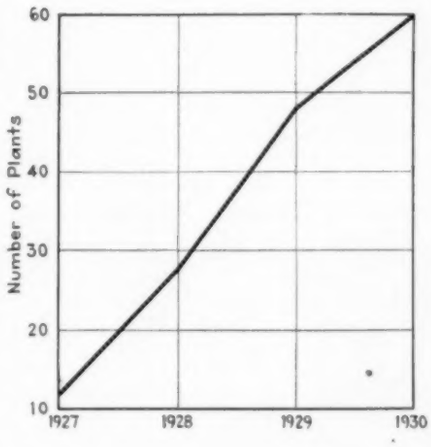
INEXPENSIVE power has been one of the important contributors to the supremacy of American industry. It has made possible mass production with consequent decrease in manufacturing cost. It will continue to contribute its share in the commercial competition of the future. Industry has only begun to tap its vast resources.

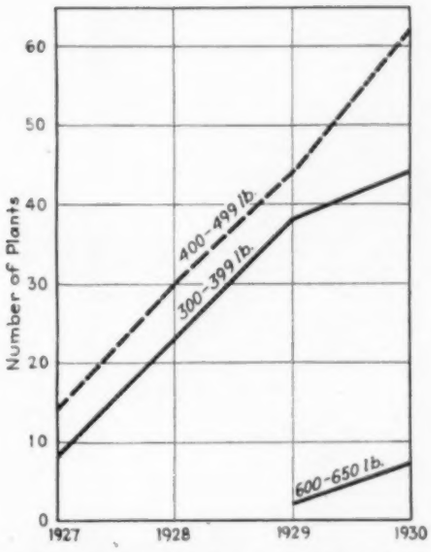
The past decade has witnessed great advancement in the art of power generation and utilization in this country. It is worth while now, when industrial activity has slackened its pace, to glance in retrospect at what has been accomplished in preparation for the time when the tempo of industry increases.

Largely due to economic factors, public utilities have been the leaders in the development of the technology of power generation, especially since 1919. Firstly, they have been able to obtain the capital required to build generating plants and, secondly, because power is their finished product and stock in trade, it had to be made efficiently and economically to yield a return on the investment. There resulted a race to attain, with each succeeding plant designed, a greater thermodynamic efficiency. It is thought that this objective has developed a perspective in some cases that overlooked the monetary efficiency of the capital involved. Of course, the great increase in the cost of fuel—particularly bituminous coal—after the World War was a compelling factor urging the curtailment of losses theretofore believed inherent in power plant operation. As a measure of the accomplishment, in 1931 there was used 1.56 lb. of coal or its equivalent per kilowatt-hour generated by all the public utilities in this country, against 3.2 lb. in 1919. Some highly efficient plants now use a trifle less than 1 lb.

General Trends in Generation

The economy shown by these figures has been secured through the use of several devices, but principally by the employment of high steam pressures and temperatures, the use of which has been as available to industrial plants as it has been to the central stations. In 1919, the latter were being designed to operate on steam at 250-300 lb. pressure and at 500-550 deg. F. Their thermal economy was about 20,000-17,500 B.t.u. per kilowatt-hour. By 1925, stations were operating at 550-650 lb. and in the following year at 1,200 lb. Steam temperatures then were 650-750 deg.; thermal economy had dropped to 14,500 B.t.u. Today, pressures have risen to 1,450 lb., temperatures to 825 deg., and economy has fallen to 12,000-11,000 B.t.u. The present ultimate is represented by 5,000-lb. pressure in one experimental installation and 1,000 deg. temperature in another for research purposes.





Cumulative Number of Industrial Plants Placed in Service 1927-1930. Above, Pulverized-Fuel Fired, and at Left, High-Pressure Steam Plants

Progress in the use of higher steam pressures and temperatures by industrial power plants has lagged behind that of central stations. Prior to 1925, few industrial plants generated 300-lb. steam. Today, there are between 200 and 250 plants using steam at that pressure or higher. The higher pressures employed fall into two general groups, one at 400-500 lb., the other 600-650 lb., depending on the requirements of the individual plant. Some are using 1,200-1,500 lb. and the present maximum is 1,840 lb. At the same time steam temperatures have been increased.

Higher steam pressures and temperatures are responsible for even greater changes in the industrial power field than in the central stations by materially increasing the yield of by-product energy. Some of the modern industrial plants generating electrical energy have greatly bettered the economy of the central stations. The latter lose to the condenser circulating water about 50 per cent of the heat of the fuel fired. In the industrial plant, designed to operate non-condensing, the exhaust steam from the turbine engines is discharged at some pressure above atmospheric to a process that can use it at that pressure. The electrical energy generated by reducing the pressure of the steam from that of the boiler to that of the turbine exhaust is a byproduct of that reduction and is obtained at an economy of about 4,000-4,500 B.t.u. per kilowatt-hour.

The increasing extent to which high steam pressures have been used in industrial plants since 1927 is seen in the chart above, giving the cumulative total through 1930, the last year for which statistics are available. The number shown probably is not complete by any means, as statistics are not sufficiently comprehensive. The upward trend, however, is clearly evident. Increases in steam temperatures have followed the same trend.

Improvements in Industrial Plants

Proceeding from this brief general survey to a specific consideration of steam generation in the industrial field

Industrial Plants Built in 1927-1930 Generating Byproduct Energy

300-399 Lb. Group Plant	Boiler Pressure, Lb.	Extraction Pressure, Lb.
Aberfoyle Manufacturing Co.	300	5
American Glanstoff Corp.	300	*
American Locomotive Co.	300	*
Bergstrom Paper Co.	350	5
Canada Paper Board, Ltd.	300	15
Canadian Salt Co.	350	40
Davey Co.	300	*
Eagle Paper Co.	300	15
Emery Industries, Inc.	300	*
Fort Howard Paper Co.	325	*
Glen Alden Coal Co.	300	15 abs.-3.7 abs.
Globe-Wernicke Co.	300	*
Grays Harbor Pulp & Paper Co.	375	45-140
Halftown Paper Board Co.	300	30
Hanes Knitting Co.	300	35
John Heald Paper Co.	325	25
Industrial Rayon Corp.	300	20
Inland Steel Co.	300	*
Laurentide Co., Ltd.	335	*
Mead & Johnson	300	10
Packard Motor Co.	325	85
Perry Knitting Co.	300	5
R. J. Reynolds Tobacco Co.	385	10
Swift & Co.	300	*
Tennessee Coal, Iron & R.R. Co.	375	*
Thunder Bay Paper Co.	385	125-25
Titanium Pigment Co.	300	40
Weyerhauser Timber Co.	325	125
400-500 Lb. Group		
Ajax Rubber Co.	400	170
Albermarle-Chesapeake Co., Inc.	450	*
American Tobacco Co.	450	90
Anheuser Busch Co.	500	125
Anglo-Canadian Pulp & Paper Mills.	400	110
Atmospheric Nitrogen Corp.	450	*
Bethlehem Steel Co.	450	*
British Empire Steel Corp.	450	*
By-Products Coke Corp.	425	*
Calco Chemical Co.	488	*
Calumet & Arisona Mining Co.	400	*
Champion Fibre Co.	450	175
Consolidated Water Power & Paper Co.	400	125-30
DeLaval Steam Turbine Co.	400	4
du Pont Rayon Co.	450	20-75
Elliott Co.	400	2
Ford Motor Co.	425	*
Garlock Packing Co.	400	60
Gulf States Paper Corp.	450	*
Humble Oil & Refining Co.	400	*
International Paper Co.	400	*
Jones & Laughlin Steel Corp.	450	*
Miami Copper Co.	425	85-25-5
Michigan Limestone & Chemical Co.	400	*
Minnesota & Ontario Paper Co.	450	135
National Cash Register Co.	450	*
National Electric Products Co.	425	125
Nekoosa-Edwards Paper Co.	400	*
New Haven Pulp & Board Co.	400	80-100
Olympic Forest Products Co.	450	*
Pittsburgh Steel Co.	425	*
Proximity Manufacturing Co.	445	150-20
Rhinelander Paper Co.	415	125-20
St. Lawrence Paper Mills, Ltd.	425	*
Paul A. Sorg Co.	400	50-20
Standard Oil Co. of Indiana	475	*
John Strange Paper Co.	400	125
Sylvania Industrial Corp.	400	*
Tennessee Eastman Corp.	450	*
Tobacco By-products Co.	425	105
Viscose Co.	450	150-15
West Vaco Chorine Products Co.	400	75
West Virginia Pulp & Paper Co.	425	150

*Extraction pressure unknown.

Industrial Plants Built in 1927-1930 Generating High-Pressure Steam

Company	Location	Boiler Pressure, Lb.
West Virginia Pulp & Paper Co.	Tyrone, Va.	600
Sinclair Refining Co.	Houston, Texas	600
Westinghouse E. & M. Co.	Essington, Pa.	625
Ashton Valve Co.	Cambridge, Mass.	650
Champion Coated Paper	Hamilton, Ohio	650
Hancock Inspirator Co.	Boston, Mass.	650
Waldorf Paper Products, Inc.	St. Paul, Minn.	650
Louisiana Steam Products, Inc.	Baton Rouge, La.	670
Firestone Tire & Rubber	Los Angeles, Calif.	710
Diamond Alkali Co.	Painesville, Ohio	730
Standard Oil Co. of N. J.	Bayway, N. J.	730
Solvay Process Co.	Solvay, N. Y.	750
Nathan Mfg. Co.	New York, N. Y.	800
Masonite Corp.	Laurel, Miss.	1,200
Consolidated Ashcroft, Hancock Co.	Bridgeport, Conn.	1,250
Ford Motor Co.	Fordson, Mich.	1,400
Crosby Steam Gage & Valve Co.	Boston, Mass.	1,500
Philip Carey Mfg. Co.	Lockland, Ohio	1,800
Diamond Power Specialty Corp.	Detroit, Mich.	2,500

during the last half decade, there are found to have been many important changes and improvements, other than higher pressures and temperatures, over previous practice. The capacity of the individual boilers has been increased. Whereas an output of 50,000 to 70,000 lbs. of steam per hour from one unit was considered sufficient for the volume of space occupied in the boiler house, today units are in use which develop 150,000 lb. Of couse, the equipment used to obtain this higher capacity is more elaborate, but no more complicated, than that formerly employed.

The increase in capacity has been partially obtained by more efficient use of the heat liberated in the furnace. The practice of using economizers to heat the feed water, by reducing the temperature of the gases expelled up the stack, is an old one in industrial plants. It has been amplified to take the water at 212 deg. F., and higher, instead of at 70 to 100 deg., and heat it to the saturation temperature of the steam. To effect the capture of a greater quantity of the heat otherwise lost to the stack, air preheaters are added between the economizer and the stack. They return heat recovered from the flue gases directly to the furnace in the medium of the air for combustion. In terms of temperature, air at 300-500 deg. F., instead of 70 deg. or less, is supplied a furnace having an average temperature of 2,000 to 2,500 deg.

Another factor responsible for increased unit output is the higher rates of heat transfer used in furnace and boiler design in the last five years or so. These higher rates have more than compensated for the increased capital cost of plant which higher pressures and temperatures would have produced otherwise.

Fueling Considerations

The growth of the capacity of individual industrial boiler units has developed concurrently with the increased use of pulverized fuel. The high heat liberation rates possible with this type of fuel have required a furnace construction embodying water-cooled walls. They absorb radiant heat formerly taken up by the solid masonry walls and then largely dissipated to the boiler-room air. The quantity of heat absorbed depends on the designed fraction cold of the furnace, but the wall tubes of a fully cooled furnace will increase the output of the unit by 25 to 30 per cent.

The chart on p. 195, showing the cumulative industrial boiler capacity fired by pulverized fuel installed between 1927 and 1930 inclusive, illustrates the trend to this type of fuel. Again available statistics may not be complete. It is interesting to observe that pulverized fuel was first used by the cement industry, the equipment for its preparation and use developed to its present perfection by public utilities, and now industry in general turns to it for an economical method of fuel utilization. A typical example of a modern boiler unit fired with pulverized fuel and capable of developing large outputs of high pressure and temperature steam is shown in the cut on the opposite page.

The impression must not be gained that firing coal in the pulverized state is the only present-day efficient method available to the industries for burning fuel. Bituminous coal fired on underfeed stokers, certain bituminous slack coals and anthracite on chain-grate stokers, fuel oil and natural gas in appropriate burners all offer opportunities to obtain high efficiencies. They may be fired with preheated air, but the optimum air temperature in the case of stoker equipment will be less than that practical with pulverized coal. Whether equally high capacities are developed as with pulverized fuel depends on the kind of fuel used, the furnace design, and the burning equipment. The methods of firing all the fuels mentioned have been vastly improved in the last five years to attain greater capacity and higher efficiency, the improvements being jointly contributed by industrial and public-utility engineers.

High-Capacity Systems in Industry

The use of high-capacity boiler units in industrial plants, where the total steam load warrants the installation of only one or two such units, need not cause apprehension that all one's eggs are figuratively in one basket. A survey of about 250 boiler units, covering their service records over the last three years, reveals the availability factor of those in the pulverized fuel-fired class as 87 per cent; stoker-fired class, 83 per cent; and oil- and gas-fired class, 86 per cent. Manufacturing process equipment often does not have such high availability.

While the upper limit of the capacity of individual industrial boiler units is now around 150,000 lb. per hour and has a long way to go before it reaches the present central station maximum of 1,000,000 lb. or more, industrial use of high pressures is abreast of that of the public utilities, numerically at least, but not in the total number of 1,200-1,450-lb. boilers. It is believed a top, maybe only a temporary one, has been reached in the ascendency of pressure in central station practice. Whether industry adopts 1,200-1,450 lb. to a greater extent than at present depends entirely upon its requirements. It is thought that a maximum of 650 lb. will afford all the opportunity necessary for the pressure reduction required to develop byproduct energy.

This thought receives substantiation in the recent increase in the permissible maximum initial steam temperature for which turbines are being designed. It now develops that use of steam in turbines at an initial pressure of 1,200 to 1,400 lb. and a total temperature of 750 deg. F., with reheating of the steam

while it is yet superheated, was a device to tide over the interval between the time when 750 deg. was the highest throttle temperature turbines could safely withstand and the 825 deg. which is the present maximum. Immediately the economic advantage of 1,400 lb. and 750 deg. with reheat is seriously challenged by 650 lb. and 825 deg. without the reheat feature. Probably the next major trend will be an increase in the temperature of industrial steam from 750 deg. to 825 deg.

It must not be inferred from the context thus far that high steam pressures and temperatures have been promiscuously adopted by industry. The optimum steam characteristics cannot be selected offhand, but must be made the subject of considerable thought and study. Only the economics of each case should be used to determine what pressure and temperature will be most economical over a period of years. The fallacy of basing one's judgment on anything less than the annual cost of producing services has been analyzed in detail (*Chem. & Met.*, April, 1931, p. 239).

The requirements of central station designing engineers and the manufacturers of equipment for such stations are responsible for the advancement made by science and engineering in the development of materials suitable for handling high steam pressures and temperatures. Much knowledge of the characteristics of steam in these higher ranges has been gained by academic research. Various cycles for the expansion of steam have been ingeniously developed for central station use. All possess some merit, some more than others. Because of the time lag between the introduction of new ideas and methods for central stations and their adoption by industrial plant designers, the latter can well afford to scrutinize the real economic value of each feature before espousing it for industrial use.

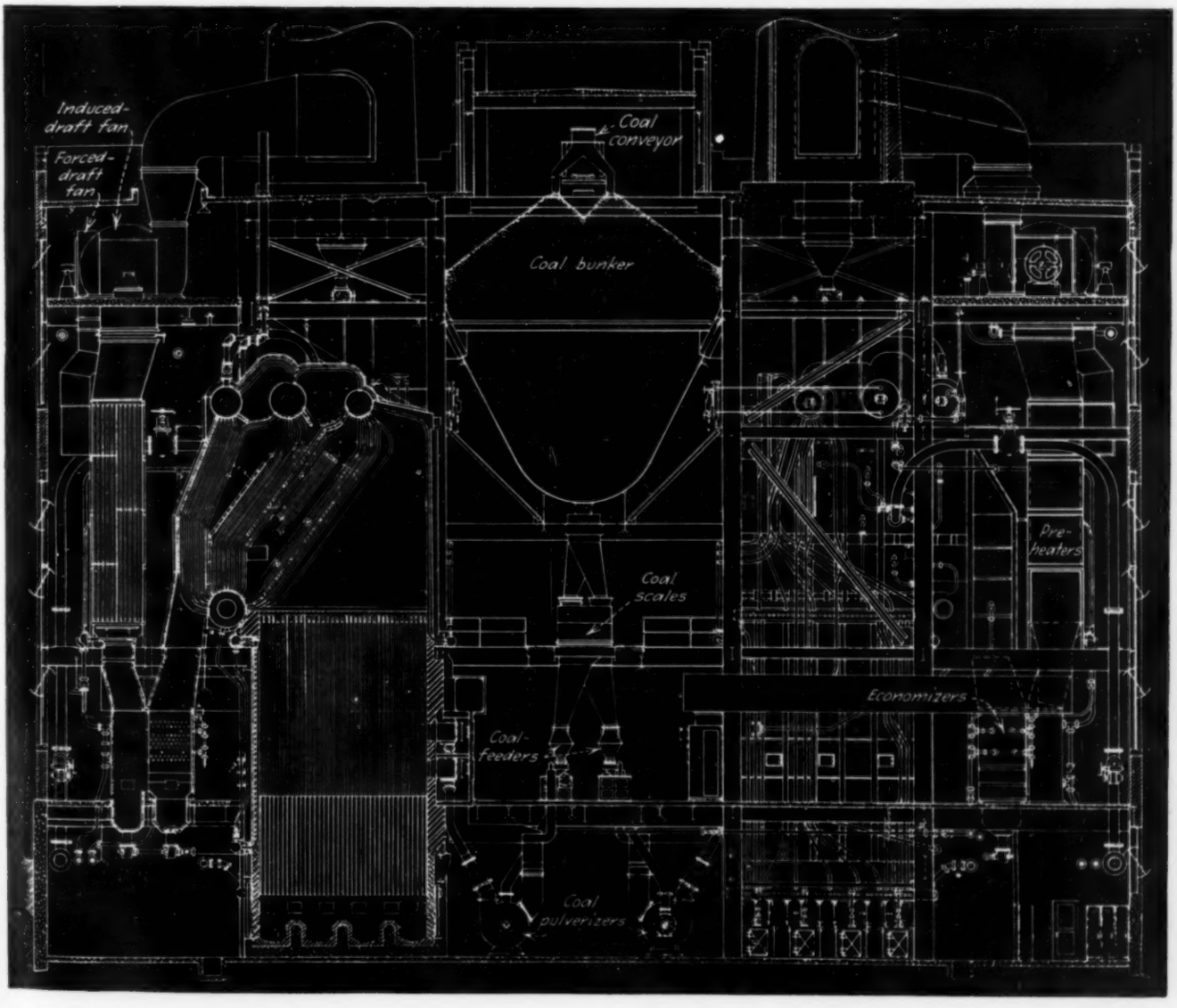
The extraction of partially expanded steam from turbine casings was first developed to increase the boiler feedwater temperature in central station practice. Industry has profitably used the principle in byproduct electrical energy generation. All of the new developments of central station designers are not likely to prove as worth while for industry. Those only should be used which can be economically justified. It is essential for industry to distinguish between an extravagant idea and one worth following with financial courage.

Process Steam Sources

The direct use of high-pressure steam for industrial processes is being curtailed wherever the technique of the process permits or production schedules allow sufficient time for completion of the reaction at a lower temperature. The trend in this direction was initiated by the desire to take advantage of the economies of byproduct energy generation and yet not increase fixed charges through greater capital investment in boiler equipment to provide steam at a higher pressure than otherwise would be necessary.

As an example of economy in direct use, a temperature of 485 deg. F., corresponding to a pressure of 600 lb., may have been found to be no more advantageous to the rapidity of the process

Modern Industrial Boiler Installation for Pulverized Fuel



Joint-Purpose Power Plant at Baton Rouge, La., Utilizing Refinery Waste and Serving Both Utility and Oil Refinery

than 445 deg., corresponding to 400 lb. Hence, boiler equipment for 400-lb. pressure is purchased at a considerable saving in capital required and annual fixed charges over that resulting from the purchase of 600-lb. construction. At the same time turbine generator units can be designed to furnish just as much byproduct energy with the lower boiler pressure. However, there are cases where the process requirements cannot be altered and high-pressure steam is a prerequisite. This is particularly true where the steam is used directly in digesters, as for exploding wood fibers in a board mill.

The direct use of steam at boiler pressure in process work is being minimized in favor of using steam bled from the turbine casing at a pressure less than that of generation. The trend of process steam pressures has been downward for the past five years, although higher pressures have been available.

The indirect use of steam in process work is increasing largely through the development of the non-contact type of heat exchanger equipment, the need of conserving and returning condensate to the boiler feed and the recovery of the sensible heat in the drips. As a heat source steam possesses a marked advantage over other agencies in that, irrespective of the rate of heat absorption, there is no decrease or increase in the temperature. Heat exchangers as now designed afford a high realization factor of the available temperature, terminal differences being as low as 3-5 deg. F.

Economic Condensate Recovery

Condensate recovery from process steam used indirectly is becoming a larger factor as boiler pressures increase. At higher steam pressures and temperatures and higher developed capacities, with consequent increased heat transfer rates, modern boiler units and their water-cooled furnaces demand pure feed water if tube renewals and outages are to be held to a minimum.

The majority of industrial power plants in the process industries have a very high percentage of boiler make-up water whose source is generally contaminated by civic and industrial wastes. The expense of evaporator equipment to provide 50-85 per cent distilled make-up is prohibitive, and chemical treatment, either cold or hot, is used, but at best it does not provide water as free from scale-forming impurities as the evaporators. Economy, too, requires that the chemical treating equipment be reduced to that necessary to handle the minimum make-up requirements. Consequently the conservation of condensate has become an important factor from the quantitative as well as the qualitative aspect of boiler water supply.

The thermal value of condensate recovery is of no mean proportions. Every million B.t.u. in the condensate returned to the boiler feed water represents 1,250,000 B.t.u. in fuel at a steam generation efficiency of 80 per cent.

Utilizing Waste Heat Sources

The recovery of waste heat in American industrial plants was confined for many years to the utilization in steam boilers of the heat in large volumes of waste gases. Probably the steel industry, more than any other, is responsible for the development of this phase of economy in industrial operation. However efficient it may have been, it was but the rudimentary start of waste heat recovery. Today many industries emitting large quantities of waste gases inert to steel and iron are using this method.

The oil industry has developed waste recovery along another line that utilizes the intrinsic heat value of its residues. One outstanding instance is a Southern refinery that uses, as boiler fuel, petroleum coke and refinery sludges, the latter being both acid and alkaline, including acid tar, wax tailings, soda and flux bottoms, and neutralized sludge. This is a great advance in the technology of waste utilization over the sawdust-fired boilers of the lumber-mill days. It is indicative of a trend that will be increasing as industry strives for greater economy in production costs.

Taking a peep into the future, it would seem as if the end of potential economy were in sight and possibly it is in one direction: *i. e.*, toward higher pressures and temperatures. Without retrogression there probably are just as many opportunities for economy in the lower pressure and temperature ranges. Many industrial process plants are throwing away daily a heat source which will develop, under certain circumstances, the same power for which they are paying monthly fuel invoices or the monthly power bills of some public utility.

An example: 100,000,000 gal. of cooling water a day, not an unusual quantity in a large establishment, can be heated by judicious use 40 deg. F., or from 60 to 100 deg. This water may be flashed into steam and made to develop 10,000 kw. The use of this quantity of energy 24 hours per day and 26 days a month would cost, if generated locally, about $17,000 for fuel per month, or would result, if purchased, in a monthly bill of $62,400. Of course, all of either of these amounts would not be saved, as the fixed charges must be paid on the equipment to effect the conversion of the waste heat into energy. While the investment would be large, the interest it would earn probably would be attractive. In any event the field offers possibilities of real economy.

The question is asked often as to when and to what extent recovery of waste heat is economically justified. The answer is that an investment in heat recovery equipment is warranted only in those cases where it will pay its own carrying charges and return as great a percentage as that same money would earn if invested in direct production equipment or processes. In detail, the expense of operating and maintaining the recovery equipment and the fixed charges on the cost of installing this equipment deducted from the cost of securing equivalent services from some other source must leave such an amount, as earnings on the new investment, as a similar investment would return anywhere else in the establishment. The minimum rate of return should be not less than 20 per cent in general, though in some cases it may be greater. It should be determined on no less a basis than annual figures, preferably averaged over a period of years.

Waste Heat and Combustion Engines

It is of interest to note a recent European development receiving some consideration over here. Certain chemical plants have available moderate quantities of highly heated water derived from exothermal processes, while others have hot waste liquors. They are being flashed into steam, drawn through a turbine driving an electric generator, into a condenser. The operating pressure in some cases is as low as 10 in. of mercury.

Progress has been made during the last half decade in the industrial power plant field to effect a better heat balance than is obtainable in all steam operation by adopting the internal-combustion

engine. In the average industrial plant generating its own power there is often an unbalanced demand for steam power and electrical energy, especially if the latter is byproduct energy. There has resulted at times an extraordinary demand for energy that can be met only by wasting steam unless condensing units are installed. A purchased power connection to take care of this situation is frequently undesirable because of its expense, and a lack of sufficient cooling water may remove the possibilities of condensing operation. Diesel-engine-driven generator units are resorted to then as an effective means of perfecting the balance.

Generated and Purchased Power

So far there have been discussed some of the changes that have taken place in the last half decade along what are considered conventional lines of industrial power and energy generation and utilization. The fundamental principle of making for one's self what one needs in the manufacture of a product is very old. It arose ages ago at a time when there was no other source of supply. It persists today, a notable example being that of a large automobile manufacturer who not only makes as much of the material necessary for the direct production of his cars as is possible, including power, but has built also his own turbine generators. The initial necessity and the subsequent practice arising therefrom developed an isolationist policy on the part of industry in general that has been reflected in the method of obtaining its power and energy requirements by self-generation.

The increasing demand for electrical energy for all purposes, the advent of the modern public utility, and the growth of the industrial phase of the development of this country brought about a change in the method of obtaining energy requirements in some industries, especially those requiring little or no steam for process purposes. At the same time the financial survival of the public utilities required that they build up their load as much as possible preferably during off-peak-load periods. There resulted inexpensive energy for many industries. The public utility policy was directly the opposite of the industrial isolationist policy, hence their plants became known as central stations.

Joint-Purpose Power Plants

This is the historical background, briefly stated, that preceded the development in the last few years of a new type of power and energy source plant serving jointly both process industries and public utilities. The advantages of such plants to industry are the absence of the responsibility of operating a power plant, a flexible source of power and energy to take care of minor or seasonal fluctuations as well as increases and decreases over a period of years, the reliability of the source, practically guaranteed continuity of service, and lower annual cost of power and energy. Few individual industrial power plants can afford to carry the spare equipment required to give equal reliability and continuity. This joint purpose plant enjoys a high load factor and a more diversified load, resulting in cheaper services to industry than industry by itself can provide.

An outstanding illustration, among many notable ones, is the 1,200-lb. Deepwater (N. J.) station jointly owned by two nationally known public utilities with a portion of the plant allocated to the services of a near-by industrial plant. The latter is supplied with steam at 180 lb. pressure as well as electrical energy. The financial arrangements call for the industrial plant to pay monthly the fixed charges on the investment in the equipment and facilities allocated to its service and its proportionate share of all direct operating and maintenance costs, including fuel. It is entitled to all energy generated by the steam that passes through the turbine assigned to its service. If the electrical energy generated is greater than the demand for it, the surplus flows into the public utility system and credit is given the industrial plant for it. Conversely, if the demand is greater than the amount generated, the public utility system is drawn upon and the industrial plant charged accordingly.

Industrial Power Exchange

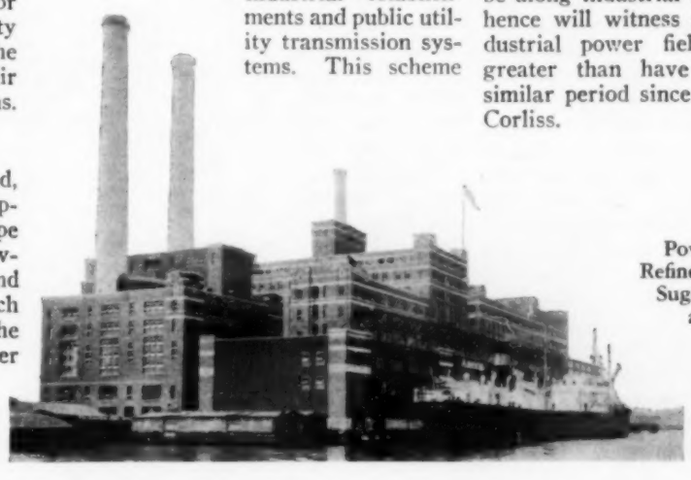
A unique arrangement between a process industry and public utility interests is exemplified at Baton Rouge, La. (see illustration, p. 198). There the industry disposes of its oil-refinery wastes to a joint-purpose plant, utilizing them as fuel, and is paid for the wastes on the basis of their intrinsic heat value. On the other hand, the joint plant supplies process steam and electrical energy to the industry, for which billing is made. Surplus energy is sent out onto the public utility's transmission system.

A variation of the foregoing is the mutual interchange of power between industrial establishments and public utility transmission systems. This scheme affords a higher load factor for the industrial power plant on the one hand and a vast reserve of electrical energy on the other. The latter feature may operate to defer the installation of additional generating equipment in the industrial plant at a time when process steam requirements are decreasing or standing still and obviate the necessity of putting in spare units. There are cases on record where industrial plants deliver 1,000,000, kw.-hr. a year of surplus energy to a public utility system. Sufficient experience is now available on the operation of such electrical interconnections between industries and public utilities to indicate that mutually satisfactory service may be rendered. It has proved in many cases to be a profitable source of monthly revenue to many establishments.

Many other instances of energy interchange might be cited. They are all indicative of a trend that is developing as the power needs of the country are being pooled. It means much for industry; cheaper power, more reliable sources, greater flexibility in operation, less investment in generating equipment, no investment in spare capacity, and the possibility of revenue from another source eventually portend a lower power cost per unit of product.

In this brief survey of industrial power generation and utilization there have been discussed the advances made in the art in the last five years. Some glimpses of what lies ahead have been obtained as the curtains veiling the future have been drawn aside. Today grave doubt exists in the minds of many as to the ultimate value of cheap industrial power in the development of the United States. Many believe technological advancement is responsible for existing economic conditions. In this they are wrong.

Present conditions are due to world-wide post-War credit inflation, a factor that was responsible for the recent increase in the demand for industrial products, which increased demand fostered technological development. There will be no reversion to an agricultural status for this country; development will be along industrial lines, and five years hence will witness advances in the industrial power field as great as or greater than have been seen in any similar period since the time of George Corliss.



Power Plant and Refinery of American Sugar Refining Co. at Baltimore

GENERATION VS. PURCHASE OF PROCESS POWER

By ROBERT V. KLEINSCHMIDT

Ammonia Department
E. I. duPont de Nemours & Co.
Charleston, W. Va.

UNLIKE the majority of unit operations with which the chemical engineer has to deal, the generation of power has been the subject of intensive study for so many years that it has reached a high degree of perfection. Much of this development, however, has been in central station work, and power plant design has been standardized along the lines that have proved most suitable in this field. Most power plant engineers have been trained in the problems of central station design, and by far the largest body of published data has been obtained from central station performance. The industrial plant engineer or the business executive who is faced with the problem of deciding whether to generate power or to purchase it from a public utility must clearly recognize that the problem of power generation in an industrial plant is very different from that encountered in a large central station. It is never safe to assume off-hand that even a large consumer can generate power as economically as a public utility; nor can it be taken for granted that generation of power by an industrial plant is necessarily uneconomical. An elaborate study by competent and disinterested engineers is frequently required to determine the exact economics of power generation, but certain factors can be pointed out as definitely favoring one course of action or the other. Some of these have been indicated graphically in Fig. 1.

There are several conditions which make the purchase of power from a public utility company economical. Unless there is some process requirement that makes power generation particularly advantageous, a new industry will ordinarily find it desirable to purchase its power—at least, until it has definitely proved its market and has perfected its technology. This will keep down the initial investment until the plant has shown itself to be financially successful. It frequently happens that in starting an industrial enterprise time is an essential factor in gaining markets and forestalling competition. In this case all the technical ability of the company is concentrated on the process, and purchase of power becomes imperative.

An established industry whose technology or market is changing rapidly—as happens, unfortunately, to be the case in the chemical industry at the present time—may find it the part of wisdom to buy power rather than risk additional capital. In fact, most industries find it necessary or desirable to expect a return from invested capital far greater than is normally allowed to public utilities. The stability of earning power of the latter is so well recognized that they are able to attract capital at relatively low rates of return.

A large market for power in a concentrated industrial area, or an unusual natural advantage such as a water power site, makes it possible for a public utility to compete very successfully with almost any independent power plant. This is strikingly illustrated by the district around Niagara Falls. Small and irregular loads are best handled by the central station.

Most public utility companies can make very attractive rates on "off-peak" and on "standby" power. Careful scheduling of manufacturing operations to take advantage of these two classes of power may make purchase of power very economical. Off-peak power is a load restricted to certain hours of the day when the system load is low. The use of such power is possible in batch and cyclical processes in such industries as paper pulp, varnish, food products, and certain metallurgical industries. The heavy heating loads are scheduled for the night hours. Some central stations have a high winter peak load in the early evening, and can well make off-peak rates for as much as 20 hours per day. An example of this sort is shown in the typical central station load curves reproduced in Fig. 2.

The use of standby power is suitable for large, steady loads which can be interrupted on rare occasions without notice. This power is furnished by the use of a portion of the standby equipment of the central station, which is required only in an emergency for the normal system load. When such an emergency arises, the standby load is dropped instantly by the central station load dispatcher. Such loads are available for all except a few hours or days per year. This type of power is well suited to electrolytic plants and to certain heating loads in which interruption of power will not seriously damage the product. The development of carrier-wave control makes possible the extensive application of these two forms of power in cases where the characteristics of the process permit their use. This gives promise of becoming, in the near future, a fruitful field for cooperation between the process industries and the public utilities.

Generation of power by an industrial plant, even in moderate amounts, may be economical, provided there is a proper coordination between process heat requirements and power supply. This coordination involves a very com-

Fig. 1—Factors Influencing Power Source in Various Industries

	Industry	Generated Power								Purchased Power				
		Waste Fuel	Waste Heat	Winter Heating	Process Steam	Direct Drives	Isolated Location	Reliable Power	Continuous Operation	Off-Peak Power	Stand-by Power	Changing Technology	Unstable Markets	Small Loads
Typical Process Industries	Cement		×	×			×	×	×		×			
	Ceramics		×				×		×	×	×			
	Chemicals		×	×	×		×	×	×	×	×	×	×	×
	Coke	×	×			×	×	×	×					×
	Gas Manufacture	×	×		×	×		×	×					
	Glass		×			×	×	×	×					×
	Leather			×	×		×							×
	Paint and Varnish		×	×	×			×		×	×	×	×	×
	Pulp and Paper		×	×	×	×	×	×	×	×			×	
	Petroleum	×	×	×	×	×	×	×	×			×		×
	Rubber			×	×	×		×	×	×		×	×	
	Soap			×	×			×	×	×	×	×		×
Other Industries	Food Products			×	×					×		×	×	×
	Iron and Steel	×	×	×		×		×	×					
	Ice and Refrigeration				×	×		×	×	×		×		
	Lumber	×			×	×	×				×			
	Meat Packing			×	×			×						×
	Metals(Non-Ferrous)		×	×			×	×	×	×	×	×		×
	Metal Working			×	×					×	×			
	Printing			×	×			×		×				×
	Textiles			×	×			×			×		×	
	Woodworking	×		×	×		×				×			

plex balance, the technical features of which place the problem of power generation in the industrial plant entirely outside the field of standardized central station practice. For example, the utilization of waste heat often available from processes involves equipment, operating technique, and economic factors entirely different from those obtaining in fuel-burning steam plants. Likewise, the use of exhaust steam for process makes necessary an entirely different physical plant layout and method of accounting from that which would be employed in a condensing station.

It can be said as a general rule that the utilization of waste heat should be undertaken only after extensive investigation of all factors involved. There

Elements of Power Costs
(Based on 5,000 full-load hours per year)

	Plant				
	A	*B*	*C*	*D*	*E*
Cost of coal, delivered, dollars per ton.....	1.50	3.00	5.00	3.00	5.00
Investment, dollars per kilowatt...	90.00	120.00	150.00	50.00	200.00*
Fuel rate, pounds per kilowatt-hr.	2.0	1.4	1.0	0.25	.....
Cost elements	Cents per Kilowatt-Hour				
Fuel.....	0.15	0.21	0.25	0.04	.....
Fixed charges, 15 per cent	0.27	0.36	0.45	0.15	0.60
Labor, repairs, supplies, superintendence, etc....	0.10	0.12	0.15	0.05	0.35
Totals.....	0.52	0.69	0.85	0.24	0.95

*Including standby coal-fired boilers to the extent of about one-half the plant rating.

have been many ill-advised attempts to utilize heat under conditions where corrosion and erosion of valuable equipment more than offset the saving of fuel. In a water-gas plant, for example, the cost of purging the waste-heat boilers may alone offset the entire value of the steam produced.

On the other hand, the generation of power in high-pressure turbines exhausting to process will almost always show a saving over the purchase of power coincident with generation of low-pressure steam for process. Under these conditions, the use of the highest pressures for which equipment is available will frequently show large savings. The importance of high boiler pressures increases rapidly as the back pressure on the process steam lines increases. When process steam is used it is essential to clear thinking that accounting methods be employed which will give a true picture of the cost of using steam at various pressures. For this purpose it usually is desirable to apportion charges for steam to various processes on an "available energy" basis.

Special conditions in certain types of plants make generation of power necessary. Sawmills normally generate all their power from waste wood fuel. Heavy forging hammers are almost universally direct-steam operated. Direct engine drives for certain processes have a flexibility, variation in speed, and reliability which is not easily obtained in an electric drive. This is particularly true of air and gas compressors and pumps operated as auxiliary services. In spite of remarkable developments in electric drives, the steam-driven paper machine is still holding its own.

Certain other factors, not in themselves pointing in either direction, must be carefully considered in making a decision on this question. If the plant is located at a considerable distance from the nearest public utility plant, interruption of service by surges and accidents to the transmission line must be given weight in comparing the reliability of purchased power with that of power generated at the plant. In a well-designed power plant, even with a minimum of standby capacity, the probability of accidental interruption of power is very slight compared with that of power surges due to thunderstorms. This danger is greatest in the case of an isolated plant served by a single line; it is practically negligible in an industrial community served by a network adequately interconnected to several generating stations. The development of superpower networks has improved this situation materially. However, in process industries involving exact coordination of many machines, interruption of power, even for a few seconds, may necessitate a complete shutdown involving hours of delay and the loss of valuable material in process.

One is sometimes tempted to consider generating a portion of the required power and buying the rest. Careful study almost always shows this to be uneconomical under present methods of rate-making. Such cases arise when a portion of the load can be very economically generated as byproduct power from process steam. Under this circumstance it may seem advisable to avoid excessive investment in boilers or other equipment by means of a tie-in with the public utility system to provide for occasional large power demands. Such variable loads take a high rate, since it is assumed to be necessary to maintain equivalent idle equipment in the central station. In a few instances public utility companies have recognized that these occasional loads throughout an extensive system will largely balance out, and justify a competitive rate. Where this has been done it has proved advantageous to all parties concerned.

A brief analysis of the items entering into the cost of generating power will make possible a rough comparison of the probable cost of generation with available rates for purchased power. The two major items in the cost of power are fixed charges and fuel. As the cost of fuel increases, it becomes economical to install such fuel-saving devices as air heaters, economizers, high-vacuum condensers, and stokers or pulverized fuel systems, so that the investment cost of a well-designed plant will increase with the cost of fuel. Operating costs are low but extremely variable, depending on labor cost. The accompanying table of elements of power costs shows the magnitude of the major cost elements for five typical power plants. Plants *A*, *B*, and *C* are complete condensing power plants designed for fuels of various prices. Plant *D* is a byproduct power plant in a small paper mill. Plant *E* is a waste-heat installation in a large cement mill, indicating an excessive item for repairs due to dust and bad feed-water conditions. The figures are based on generating units in the range from 1,000 to 5,000 kw. Below these sizes the investment cost and fuel rates both increase appreciably.

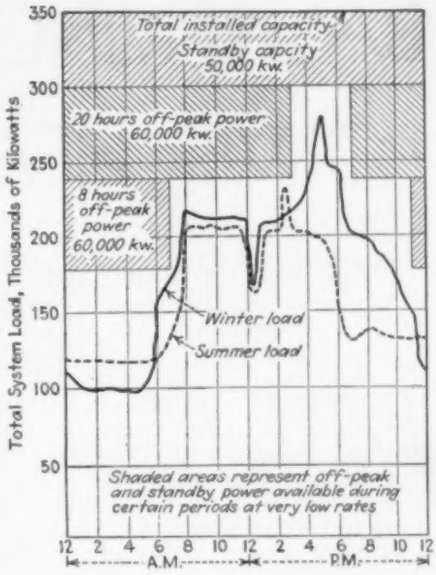


Fig. 2—Typical Central Station Load Curves Showing Available Off-Peak and Standby Power

Aside from the technical points specifically mentioned, the decision as to the most economical power supply may depend somewhat on the relative bargaining power of the industrial company and of the public utility. Many industrial power plants have been laid out in detail only to be pigeonholed when the public utility established competitive rates. Conversely, industrial power plants have shown savings as high as 100 per cent annually on the investment. It must be borne in mind, however, that under equally favorable conditions a large power plant with a diversified load, operated by men who have no other interest but the economical generation of power, can successfully compete with a power plant operated as an adjunct to a complex manufacturing enterprise. If the industrial power plant is only a replica of the central station, it probably is uneconomical. Before deciding to generate power, the management of an industrial plant must determine specifically wherein the advantage will lie.

BALANCING A PROCESS PLANT'S POWER-HEAT LOAD

By WILLIAM E. BEACH
Industrial Engineer
Riverside, Ill.

EFFICIENT UTILIZATION of steam is a vital factor in the development and prosperity of modern industry. Plants that require steam only for power generation find their problem reduced to the consideration of a generating system of the condensing type. This system, best represented by modern public utility plants, employs many refinements, such as pressure economizers, heat exchangers, reheaters, pressure feed-water heaters, deaerating heaters, evaporators, water-wall furnaces, and the like, all designed and installed for the purpose of producing power at the lowest possible unit cost. But a system which is generating steam for both process and power use must consider the plant-process load simultaneously with the power load. Such a system frequently requires much of the above-mentioned equipment and, in addition, such apparatus as desuperheaters, automatic pressure-reducing valves, automatic electric and steam controls on the prime movers, process-water heating equipment and process pumps.

The basic principle of process-power steam development is primarily that of generating steam at a high pressure and superheat, obtaining all possible power by expanding it to one or more lower pressures applicable to the process requirements, and then extracting most of the remaining heat in process equipment before condensation or loss. From an economic standpoint, an endeavor is made to balance the process and power-steam requirements. An industrial plant so arranged that one would exactly balance the other would be an ideal of economy and efficiency. In practice, this theoretical ideal is never attained. As conditions may dictate, condensation of a greater or lesser part of the power steam must be resorted to in attaining balance.

In the average industrial plant using steam for both purposes, many variables enter into the scheme and tend to create unbalanced conditions. Among the major variable factors are those changes in operation which contribute to fluctuating power and process loads, and temperature variations, due to seasonal changes, in condensing water, the plant interior, and the feed water.

In arriving at an intelligent selection of equipment, it is first necessary to make analyses of various assumed plant-loading conditions which approximate probable future operation. Through this means one can determine whether the installation of additional auxiliary apparatus will be justified by the savings that result. Conversely, the study may disclose results which will make the added installation inimical to the entire scheme. Hence, after the basic plan has been established, the efficiency of various refinements is determined solely from a comparison of their annual charges with the economies to be derived as a result of their inclusion. Frequently certain auxiliary apparatus must be included in industrial plants, despite the fact that the inherent performance is conceded to be inimical to the scheme. When this becomes necessary, the deficiencies must be compensated for as best befits the arrangement.

The paper industry is an important user of steam for power generation and process application. As a definite example of process-power balance, consider a modern pulp and paper plant. Assume it to have a daily commercial capacity of 200 tons of sulphite pulp and 100 tons of high-grade paper. On account of losses in processing, assume 220 tons of pulp and 110 tons of paper to be the basis for analyzing the load conditions.

For the first step it is necessary to set forth, as in Table I, the maximum tonnage requirements, the units of steam per ton, and the daily process steam necessary for capacity operation. The departmental electric load is then analyzed in detail and recapitulated in Table II.

With this information prepared, together with a skeleton process diagram, the analysis of the steam balance is made for all possible conditions of operation which might ensue in actual practice. The prime-mover throttle pressure and those pressures required for processing the product form the basis of all detailed steam considerations. Many conditions of plant loading must be analyzed. There are constant maximum and minimum winter and summer loads. There are peak loads which occur at frequent intervals, equally distributed throughout the day, and of uniform duration. An example of a principal peak load occurs during each digester cooking period. There are Sunday and holiday loads with their inherent variations. These and other loadings must be analyzed separately or in conjunction with each other, in order that equipment can be selected which will be most economically suited for all conditions.

Table I—Production and Steam Estimates

	Lb. per ton	Tons Daily / Lb. daily
Pulp mill		
Bleached sulphite pulp		200
Shrinkage in processing		20
Total required		220
Paper and pulp drying		
Sulphite bond paper		100
Shrinkage in processing		10
Total required		110
Bleached sulphite pulp		90
Steam requirements		
30 lb. gage steam for drying paper	7,400	814,000
30 lb. gage steam for drying pulp	4,700	423,000
125 lb. gage steam for cooking pulp (maximum)	7,200	1,584,000
125 lb. gage steam for cooking pulp (constant load)	4,500	(990,000)
125 lb. gage steam for cooking pulp (intermittent peaks)	.....	(594,000)

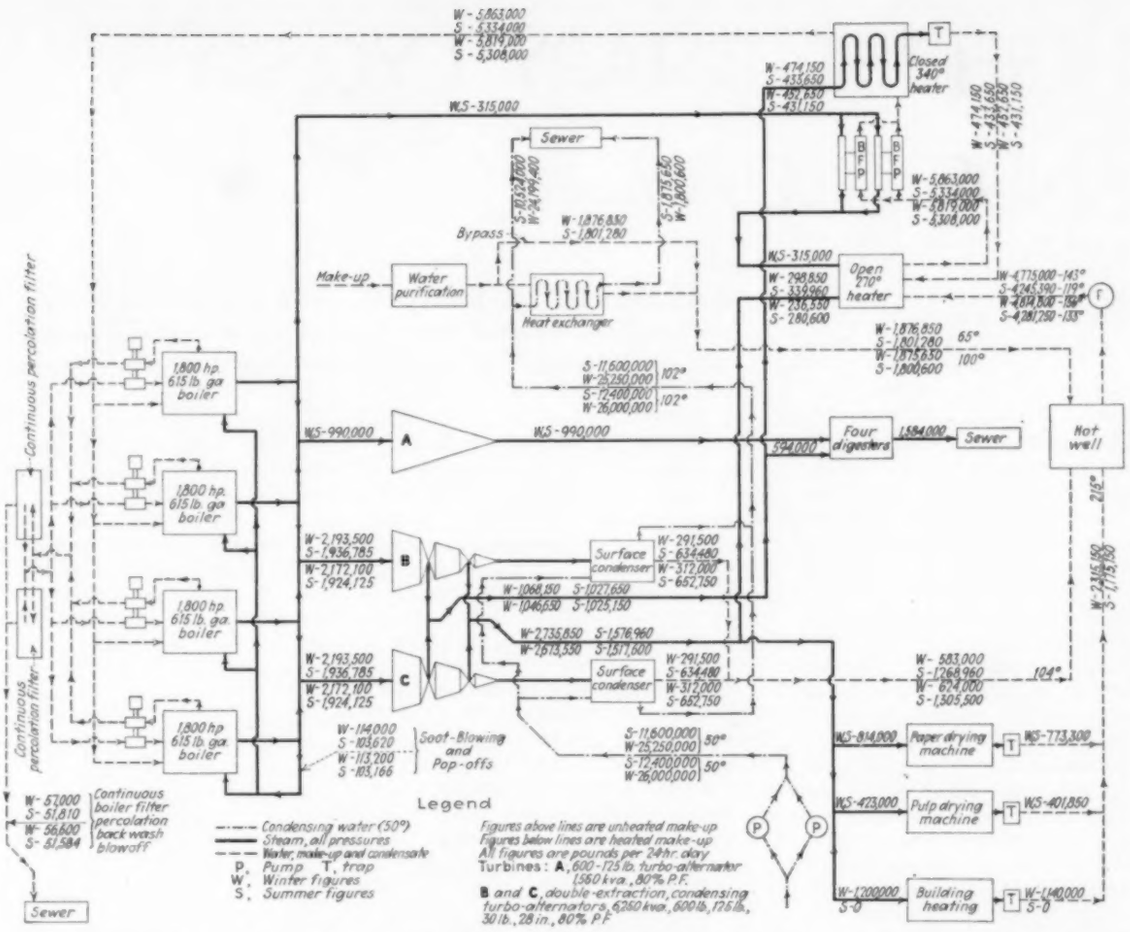
Table II—Electrical Load Summary

	Connected Horsepower	Load Factor	Demand, Horsepower
Boiler and power plant	1,920	0.34	655
Breakdown saw mill	600	0.60	360
Chipping and screening plant	1,100	0.50	550
Pumping station	400	0.90	360
Hogged fuel plant	740	0.60	436
Pulp mill including acid plant, storage facilities, digester plant, screening plant, etc.	5,607	0.64	3,596
Pulp drying machine	1,100	0.55	600
Beating plant	3,236	0.63	2,019
Paper machine	2,680	0.63	1,691
Finishing plant	605	0.46	275
Total electrical horsepower	17,988	0.59	10,542
Equivalent kw., power load	13,400		7,800
Plant lighting, kw.	.....	....	100
Total minimum electrical load, kw.	.....	....	7,900
Additional for peak loads, kw.	.....	....	2,100
Total maximum electrical load, kw.	.....	....	10,000

Superheated steam will be used for power generation and equipment will be provided for desuperheating the prime-mover exhaust. Hence, either superheated or saturated steam will be available for process heating. Generally, a high-pressure, non-condensing turbo-alternator to carry the constant process-steam load will be first choice for at least one of the prime movers in a plant of this nature. The fluctuating process-steam requirement can be derived through the medium of condensing, bleeder turbo-alternators.

In our paper plant, assume boiler pressure at 615 lb. gage; prime-mover throttle pressure at 600 lb. gage; and about 200 deg. F. of superheat (steam temperature, 700 deg. F.). Assume bleeding pressures at 125 lb. and 30 lb. gage, and condensing operation at 28 in. vacuum.

Two methods are available for deriving the electro-steam balance for any given set of basic assumptions. One



is by approximation (cut and try) which becomes extremely laborious, due to the independence of such variables as condensing and heater steam and make-up water. In computing by this method, many trials must be made, continually changing the variables and recomputing until a state of balance is reached. The other method, which is the one that is used here, employs mathematically derived formulas based on the arrangement of the equipment and the fundamental thermodynamics involved. Such formulas are sufficiently accurate for all practical purposes and yield results which can be checked easily. Although their development is inherently complicated, the results justify this difficulty.

For brevity, I have limited the analysis with respect to cold make-up water to the maximum load conditions, based upon capacity production, for both winter and summer seasons. Paralleling this, an analysis has been set forth to show how the application of additional apparatus might be of economic value to the plant operation. In the latter case, the boiler-feed make-up water is heated by being passed through a heat exchanger inserted in the condensing-water discharge.

In the appended steam-flow diagram, these results are given in detail for the four conditions: winter and summer, cold and heated make-up. The figures are summarized for the several pressures in Table III. The most severe case, steam required for winter operation with cold make-up, represents an hourly requirement of 330,000,000 B.t.u. supplied in the steam. With 630-lb. abs. steam at 209 deg. superheat, this represents a total of 10,000 boiler horsepower. To supply this we must provide four 1,800-hp. boilers, to operate at 185 per cent of rating, with one boiler held as a spare. Referring to Table III, it will be noted that the use of warm make-up water requires approximately 7 per cent more condensing steam, 2½ per cent less 30-lb. steam, and 4½ per cent less 125-lb. steam. Slightly less make-up water also is indicated for this condition. However, an over-all saving of 0.8 per cent is indicated. Specifically, a daily saving of 44,000 lb. will accrue during the winter months and one of 26,000 lb. during the summer months. This saving is worth while only if its monetary value is in excess of the annual charges on the additional apparatus.

Table III—Summary of Steam and Power Requirements

(Totals from steam-flow diagram; arabic figures are totals for cold make-up water; italic figures, for heated make-up water)

	Winter Months		Summer Months	
Pressure	Lb. Steam per Day	Kw.-Hr. per Hour	Lb. Steam per Day	Kw.-Hr. per Hour
600 lb.[1]	486,000	.....	470,430	.....
	484,800	.....	*469,750*	.....
125 lb.[2]	2,058,150	2,500	2,017,650	2,450
	2,036,650	*2,480*	*2,015,150*	*2,455*
30 lb.[3]	2,735,850	5,520	1,576,960	3,200
	2,673,550	*5,400*	*1,517,600*	*3,075*
28 in.[4]	583,000	2,010	1,268,960	4,400
	624,000	*2,160*	*1,305,500*	*4,550*
Totals..	5,863,000	10,030	5,334,000	10,050
	5,819,000	*10,040*	*5,308,000*	*10,080*

[1]Steam for boiler-feed pumps, soot blowing and blow-off.

[2]Includes digester constant load, 990,000 lb. non-condensing (kw. rate, 33.5 lb), plus bled steam for digester peaks and closed heater (kw. rate, 35 lb.).....

[3]Steam for paper and pulp machines, plant heating and open heater (kw. rate, 20.6 lb.)

[4]Steam to condenser (kw. rate, 12 lb.)

With further reference to the steam-flow diagram, considering the electric load as constant, it will be noted that as the process load diminishes, the condensing load increases. Hence, the maximum use of process steam will result in a minimum use of the condensers, obviously a most desirable condition both on account of the cost of condenser operation and because the heat in the condenser water is wasted, entirely or in large part.

In a plant that has frequent fluctuations of electrical and process loads, manual control of the various elements involved does not produce the quick response desirable for maintaining the balance suitable for each condition. In order that the flexibility of the equipment may be assured and maintained, automatic electrical- and steam-control devices are installed to regulate the power and process-steam demands. These are actuated by the load conditions, commensurate with the specific plant demands, and thus through the medium of the condensers, which function as stabilizers, act as synchronizers to maintain a balance between the power and process-steam demands of the system.

WHERE THE BINARY CYCLE STANDS TODAY

By P. W. SWAIN
Associate Editor of Power

Long incubated, the binary-vapor cycle is now emerging from its shell, seeking industrial fields to conquer. It holds real promise for process industries, but must compete with high steam pressures

PRACTICALLY SPEAKING, the binary-vapor cycle means today the mercury-vapor-steam cycle. No other is beyond the stage of academic discussion, if we except the Koenemann zinc-ammoniacate-steam cycle which is now being investigated in Germany. Of the latter a little will be said at the end of this article.

The mercury-steam cycle has been pronounced a success by prominent power engineers, yet the whole world reveals but one example to date of its commercial operation. The utility installation at the South Meadow Station of the Hartford (Connecticut) Electric Light Co., delivered more than 135,000,000 kw.-hr. in the year 1931. It seems to be definitely justified by the gradual elimination of its operating troubles with improved design, and by a heat consumption of less than 10,000 B.t.u. per kilowatt-hour. However, the interest of chemical engineers in such plants is still largely academic. For them the primary significance of the mercury-vapor-steam plant is its apparent adaptability to the needs of process industries where large quantities of power, as well as process steam, are required. There its money-saving possibilities may well exceed those in central stations.

Before discussing such applications, it will be well to review the thermal possibilities that led to the development of the mercury-steam cycle, to outline the actual hook-up briefly, and to compare it with the now widely used high-pressure steam hook-up, to which it bears a strong resemblance. After that it will be easier to evaluate its possibilities in the process industries.

The only excuse for a mercury-steam cycle, or any other binary cycle, is the need or desire to get more power out of a given fuel supply, or, conversely, to use less fuel to produce a given power output.

Only a fraction of any given supply of heat can be converted into power. The fundamental, limiting factor is the temperature range of the engine or turbine used. Carnot proved long ago that no plant can turn into power a larger fraction of this heat than is expressed by the ratio $\frac{T_1 - T_2}{T_1}$, where T_1 and T_2 are the absolute temperatures, respectively, of the fluid entering the first engine (or turbine) and that leaving the last in the cycle. For example, if the fluid or vapor enters the first turbine at 500 deg. F. (960 deg. abs.), and leaves the last at 100 deg. F. (560 deg. abs.), the limiting fraction is $\frac{960 - 560}{960} = 0.417$, or 41.7 per cent. Within these limits, no conceivable plant can do better, and most will do far worse.

One problem, then, is to increase T_1, or decrease T_2, or both. In both the steam plant and the mercury-steam plant, T_2 will be $212 + 460 = 672$ deg. abs. for atmospheric exhaust, and not less than $80 + 460 = 540$ deg. abs. for the lowest practicable exhaust vacuum in condensing operation.

The top temperature, T_1 is run up to $750 + 460 = 1{,}210$ in the average central station, and may reach $1{,}000 + 460 = 1{,}460$ deg. abs. in a few experimental installations where the resulting difficulties with piping and valve materials can be faced.

Assume for the moment (to permit easy comparison) that 880 deg. F. (1,340 deg. abs.) is the present limit in this direction. Then the non-condensing steam plant would appear to have an efficiency limit of $\frac{1{,}340 - 672}{1{,}340} = 50$ per cent, and the condensing plant, $\frac{1{,}340 - 540}{1{,}340} = 60$ per cent.

Actual steam plants cannot come within gunshot of these figures. Why? The answer is well known to power engineers. To approach the Carnot ratio, practically all of the heat must be delivered to the vapor at the top temperature, T_1, and extracted at the bottom temperature, T_2. The latter condition exists in the steam plant, but not the former, for steam at 880 deg. F. is highly superheated, even at 1,000 lb. pressure. At this pressure most of the heat enters during evaporation at 547 deg. F. (1,007 deg. abs.). This temperature, rather than 1,340 deg. abs., is the measure most nearly applying in the Carnot ratio.

To use 880 deg. F. upper temperature in tune with Carnot's conception, the liquid must evaporate at that temperature in a practicable boiler. Mercury meets this requirement.

A boiler pressure no higher than 70 lb. gage need be carried to produce saturated mercury vapor at 880 deg. F. Mercury also has a satisfactory ratio of latent to specific heat, which is desirable for reasons which space does not permit expanding here.

Finally, mercury is stable at this temperature, and does not corrode steel. Hence its selection. Many other substances have been considered and found wanting for this application. True, mercury is costly, but the mercury investment is kept within reasonable limits by a special boiler design with little liquid-containing space. Again, mercury is poisonous, but the mercury cycle, as developed at Hartford under the sponsorship of the General Electric Co., is entirely sealed, except at one turbine shaft packing which is under vacuum.

The simplified hook-up shown in Fig. 1 corresponds in part to that existing at Hartford. In the steam end of the cycle, however, changes have been indicated, permitting a supply of process steam at 10 lb. gage pressure. The diagram is thereby adapted for process industry work. Such a hook-up permits a maximum utilization of the temperature range between the mercury at 880 deg. F. and the temperature required in the process steam. In other words, this arrangement permits as high a T_1 as can otherwise be obtained, and a maxi-

Fig. 1—Simplified Hook-Up of Mercury-Vapor-Steam Plant Supplying Process Steam for Manufacturing

Mercury boiler
Mercury vapor (70 lb. gage 880 deg. F.)
Mercury turbine
Mercury vapor (0.8 lb. abs. 445 deg. F.)
Mercury condenser (steam boiler)
Steam (280 lb. gage, saturated)
Feed water
Liquid mercury
Superheater
Steam (280 lb. gage superheated)
Moderate-pressure steam turbine
Steam to process or condenser (10 lb. gage to process or 0.3 lb. abs. to condenser)

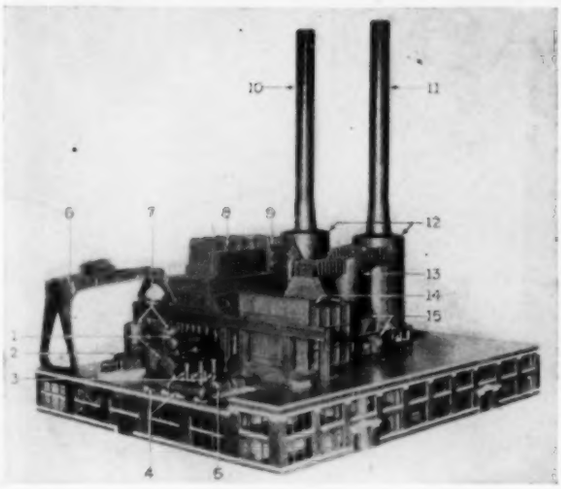


Fig. 2 — Model of Mercury-Vapor Plant Under Construction at Schenectady

(1) Deaerator; (2) Mercury Turbine-Generator; (3) Feed-Water Heaters; (4) Evaporators; (5) Steam Turbine-Generator; (6) Crane; (7) Condenser Boilers; (8) Mercury Boiler; (9) Air Preheater; (10) Mercury Boiler Stack; (11) Steam Boiler Stack; (12) Induced-Draft Fans; (13) Air Preheater; (14) Steam Boiler; (15) Blowers.

mum utilization of the possibilities of that T_1, while T_2 is as low as is consistent with the needs of the hypothetical process industry.

It will be noted that mercury at 880 deg., but at the very moderate pressure of 70 lb., is delivered to a mercury turbine which exhausts at high vacuum to a mercury condenser, which is, at the same time, the steam boiler. In spite of the high vacuum, the mercury exhaust temperature is high enough to produce steam at 280 lb. pressure. A superheater for this steam is shown, but need not be discussed here, as it has little effect on the theoretical cycle, although it is desirable for practical reasons.

The superheated steam passes to a turbine from which it exhausts at 212 deg. F., or slightly higher, to process, or at about 80 deg. to a condenser in plants where process steam is not required. It should not be assumed that the pressures and temperatures shown are standard, or even most desirable for some given set of conditions. They are merely illustrative.

If the set-up shown in Fig. 1 is operated condensing, the result is an increased delivery of power per pound of fuel burned. Paradoxically, the increased power is obtained at a greater net fuel cost, because the condenser throws away heat which might be salvaged in a process and thus credited to power production.

Considered as a power plant alone, the mercury-steam plant is extremely efficient, that at Hartford averaging as low as 10,100 B.t.u. per net kilowatt-hour for a year's operation. This is equivalent to 0.7 lb. of coal per kilowatt-hour.

For purposes of comparison, Fig. 3 has been adjusted to correspond as closely as possible to Fig. 1. It shows a high-pressure steam plant superimposed upon a low-pressure plant. In the same way, the hook-up shown in Fig. 1 may be considered as a mercury-vapor plant imposed upon a low-pressure steam plant with the low-pressure boiler removed. Both of these arrangements are possible and practicable in many cases. In both cases the power produced per pound of coal burned is definitely increased by the high-temperature addition, but the mercury produces a far greater addition than the high pressure.

Assuming a process plant with a given process-steam and power load, and assuming that the first cost and operating reliability of both mercury and high-pressure plants are established (which is generally admitted), it must not be concluded that either of these installations is desirable in all situations. To settle the point, at least one question must be answered: Do we need more power than can now be obtained as a byproduct of moderate-pressure steam passing through a turbine, and then to process? In other words, do we now produce all needed power without blowing any steam through the roof, and without wasting any to condenser circulating water? If so, nothing whatever is to be gained by the use of mercury vapor or high pressures.

If, on the other hand, the local utility will arrange to absorb excess power, or if the present low-pressure plant requires the waste of some steam to the roof or to the condenser, or if a substantial amount of power must be purchased to avoid these losses, high pressures or mercury may offer savings. If the desired condition can be achieved by going to high-pressure steam, there is little argument for the use of mercury. The field for mercury in process plants is therefore limited strictly to those where high-pressure steam will not achieve the desired results. It is believed that there are a substantial number of such plants.

Such a situation is now being capitalized by a plant under construction to supply the General Electric Co., in Schenectady, with steam, and to pump power into utility-owned lines. A model of the plant appears in Fig. 2. The plant will be operated by the utility, but fundamentally the arrangement is that shown in Fig. 1, with somewhat altered pressures and temperatures.

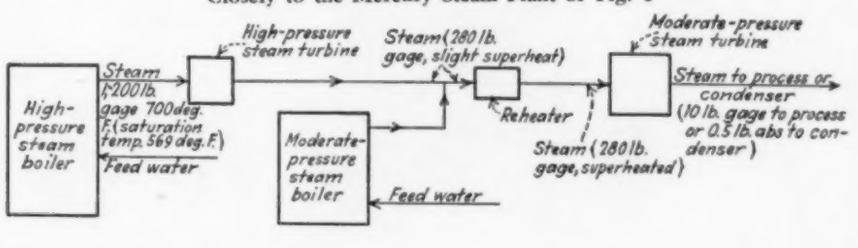
I believe that a similar set-up could be profitably considered by certain large process establishments where the present or expected power requirements are greatly in excess of those that could be produced as a true byproduct, using boiler steam at existing plant pressures.

Both the mercury and high-pressure plants may be installed originally as shown, or the high-pressure and mercury sections may be superimposed upon existing low-pressure plants. This addition of a "top" not only saves fuel but often enables the additional power capacity to be obtained at a lower investment cost (at least in the case of high pressure) than would be possible if additional low-pressure capacity were provided. The problems involved are highly technical, and their solution can be reached only by a power engineer skilled in this field.

In his hands should be placed information including: (1) Typical daily load curves for process steam demand for the various seasons at the several required pressures; (2) similar load curves for power; (3) data on the existing plant; (4) rate schedules for purchased power; (5) possible market and rate for the disposal of excess power produced. With these data it should be possible to tell whether a mercury installation offers promising returns.

For lack of space, it will not be possible to describe here the zinc-ammoniacate cycle mentioned at the beginning of the article. It should be noted, however, that it is a true chemical cycle, involving continuous synthesis and breakdown of chemical substances. By utilizing chemical reactions, it very ingeniously permits the production of a superheated vapor without actually making the vapor undergo the superheating process. Thus the vapor is "born" at the top temperature, fulfilling Carnot's objective in a way he never dreamed possible. Like the mercury-steam cycle, Dr. Koenemann's cycle utilizes T_1 to the utmost. Although his work is still in the experimental stage, it seems to hold great promise because the chemicals used are much cheaper than mercury.

Fig. 3—Combined High- and Low-Pressure Steam Plant Corresponding Closely to the Mercury Steam Plant of Fig. 1


High-pressure steam boiler
Steam (200 lb. gage 700 deg. F. (saturation temp. 569 deg. F.)
Feed water
High-pressure steam turbine
Steam (280 lb. gage, slight superheat)
Reheater
Moderate-pressure steam turbine
Steam to process or condenser
(10 lb. gage to process or 0.5 lb. abs to condenser)
Steam (280 lb. gage, superheated)
Moderate-pressure steam boiler
Feed water

HOW THE POWER FACTOR MAY BE IMPROVED

By R. H. ROGERS

Industrial Engineering Department
General Electric Co.
Schenectady, N. Y.

AN ALTERNATING-CURRENT power system carries amperes and volts and delivers kilowatts of power. If amperes and volts are strictly working together, the total kilovolt amperes and the kilowatts will be the same and the power factor is said to be unity. If current lags behind or leads voltage, more current must be carried to get the same work done; this additional current is called lagging or leading reactive kva., as the case may be. The total kva. in the system now exceeds the kw. and the ratio of kw. or actual power to total kva. or apparent power is lagging or leading power factor. Thus

$$\frac{\text{Kw.}}{\text{Total Kva.}} = \text{P.F.},$$

which may be expressed as a per cent or as a decimal. It is clear that power factor can never exceed 1, or unity, because the total kva. will always be as much as or more than kw.

The total kva. is not the arithmetical sum of kw. and reactive kva.; it is the square root of the sum of the squares of these values and is shown in Fig. 1 for lagging and leading power factor. Giving values to typical conditions in Fig. 1, we have actual power factors represented as in Fig. 2.

Any device which takes magnetizing current from an a.c. system is responsible for some lagging reactive kva. Among the more common devices of this nature are induction motors, transformers, and solenoids. They borrow current and put it back in every half cycle as it is required for magnetizing the iron during rising voltage values and as it is regenerated by the decaying flux during the period of falling voltage value. This current, called wattless current, does no useful work, but copper must be provided for carrying it in every inch of every circuit involved, if voltage drop is to be kept to a reasonable figure.

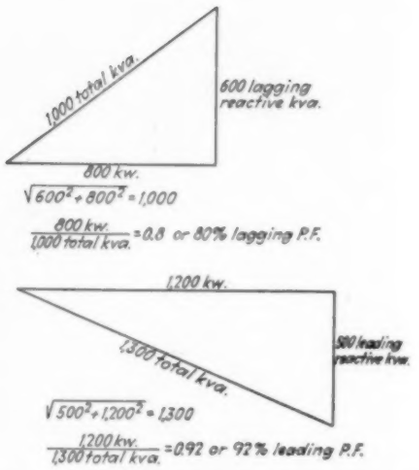
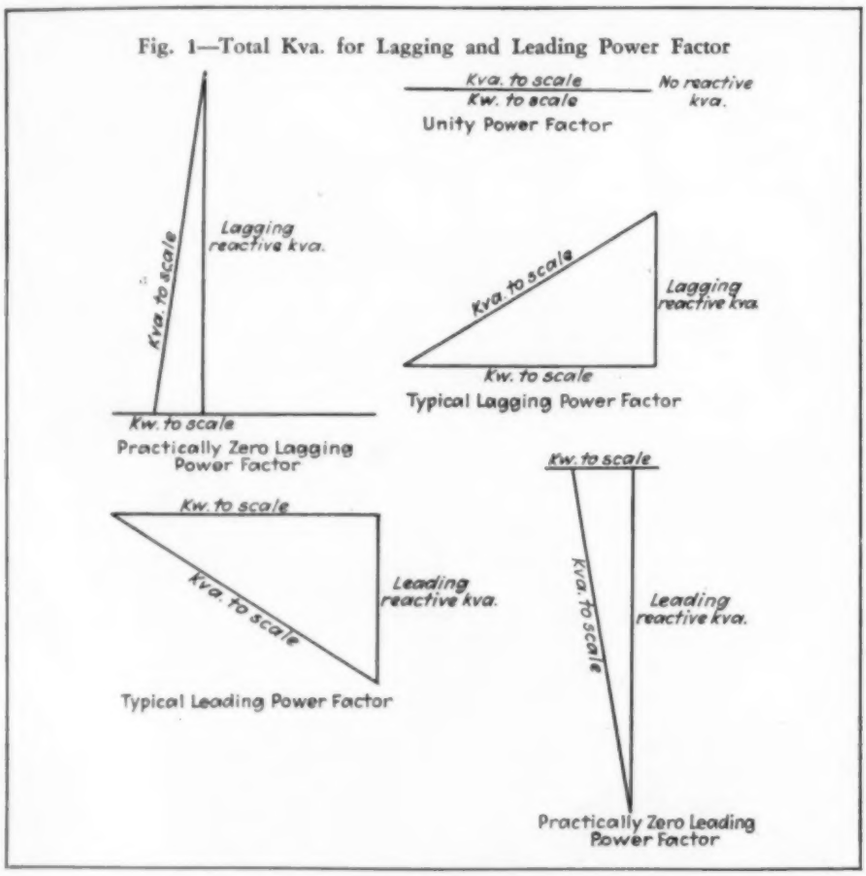


Fig. 2—Giving Values to Typical Conditions in Fig. 1. We Have Actual Power Factor Represented

Certain equipment provides leading reactive kva., and wattless current leading the voltage is, by itself, just as bad as lagging reactive kva. That is, leading power factor alone is no better than the same value in lagging power factor. However, leading power-factor synchronous motors, synchronous condensers, and capacitors used judiciously neutralize lagging reactive kva. and bring an otherwise poor power factor nearer to, if not quite to, unity. Such a condition may be represented as in Fig. 3.

The principal types of electrical equipment used in industry have characteristic power factors which are in some cases varied by load or design. Loads that are inherently of the unity power factor character are resistance loads, such as lighting systems, resistance furnaces, and resistance heating devices of various kinds. Synchronous motors with normal excitation are rated unity power factor. Such loads produce marked improvement in what would otherwise be low power factor by increasing the total kilowatt load without increasing the lagging reactive kva.

Fig. 1—Total Kva. for Lagging and Leading Power Factor



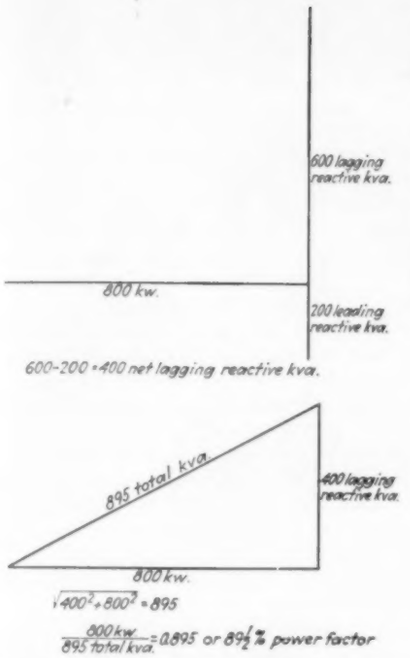

600 lagging reactive kva.
800 kw.
200 leading reactive kva.
600-200 = 400 net lagging reactive kva.
895 total kva.
400 lagging reactive kva.
800 kw.
√400² + 800² = 895
800 kw. / 895 total kva. = 0.895 or 89½% power factor

Fig. 3—Leading P.-F. Synchronous Condensers and Capacitors Used Judiciously Neutralize Lagging Reactive Kva. and Bring an Otherwise Poor P. F. Nearer to, If Not Quite to, Unity

This effect in general is shown in Fig. 4.

Induction motors have more or less lagging power factor according to speed and load. The typical power factors for 220-, 440-, and 550-volt induction motors of normal design are indicated in the accompanying tabulation. The

Table I—Typical Power Factors for 220, 440 and 550-Volt Induction Motors of Normal Design

Horsepower	R.P.M.	Half Load	Full Load
1	3,600	0.72	0.87
1	900	0.52	0.70
5	3,600	0.80	0.90
5	600	0.48	0.70
25	1,800	0.80	0.90
25	600	0.42	0.67
100	1,800	0.88	0.94
100	600	0.76	0.875

table clearly shows the desirability of making use of high-speed induction motors wherever possible, since a typical example shows 0.67 power factor for a 600-r.p.m. motor and 0.90 for an 1,800-r.p.m. motor. The undesirable effect of underload is also shown in the tabulation, the effect being more marked with slow speed machines. A typical example is 0.67 power factor at full load and 0.42 at half load.

Other sources of lagging power factor are induction furnaces (which, however, usually are equipped with means for correction), solenoids, and underloaded transformers. Equipments that tend to produce leading power factor and are therefore used for power factor improvement are synchronous motors with greater than normal excitation, synchronous condensers, and capacitors. Synchronous motors which are operated to give, say, 0.9 or 0.8 leading power factor are acting partially as generators and hence the mechanical load must be reduced to avoid excessive heating. Table II, in which each group indicates a frame size, shows the necessary reduction in horsepower for various leading power factors.

Table II—Reduction in Horsepower for Various Leading Power Factors

Horsepower	Leading Power Factor		
25	Unity		
22		0.9	
20			0.8
50	Unity		
45		0.9	
40			0.8
100	Unity		
90		0.9	
75			0.8
200	Unity		
180		0.9	
150			0.8

There are a number of reasons why high power factor is desirable in a plant whether the power is developed within the plant or is purchased. Suppose a system has been laid out with enough of copper in everything involved to give a reasonable voltage drop when the load has the calculated power factor. If the load is increased at the same power factor or if the power factor is lowered, the voltage drop will be greater. This will cause motors to develop less torque at

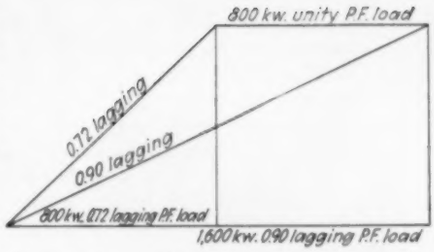
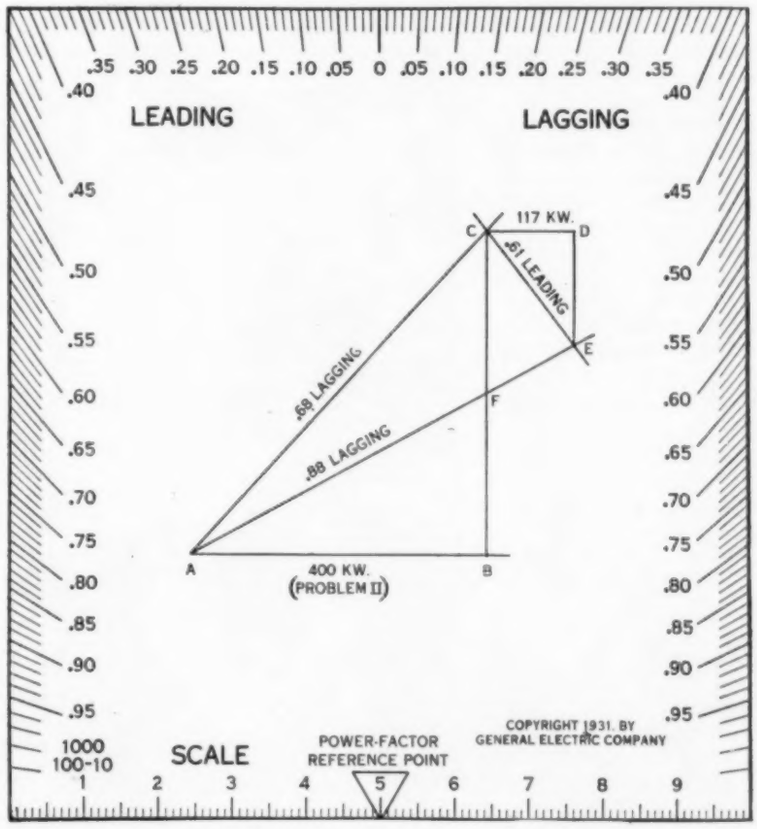


Fig. 4—Improving Power Factor by Increasing Total Kilowatt Load Without Increasing Lagging Reactive Kva.

starting, will cause excess voltage dips when large motors are started and when overloads develop. Induction motors will have greater slip. Undervoltage relays will stop motors more frequently. Lights will be below normal brilliancy and will be dimmed more often and to a greater extent. All these symptoms point to reduced production.

Rate structures for purchased power usually include demand charges and energy charges. The demand charge may be based on a 15-minute total kva. demand, which in some cases determines the demand charge for the following twelve months. The energy charge is for kilowatt hours shown on the kilowatt-hour meter. It is good economy to keep the demand close up to the ruling demand once that is established or, in other words, to keep the ruling demand down close to the average demand. With lower power factor, when it is necessary to meet a peak kw. demand, the total kva. will run up to an exces-

Fig. 5—Power-Factor Plotter Is Helpful in Solving Problems



sive value because of the large reactive kva. component. High power factor keeps kw. loads and total kva. demand close together and the ruling demand is not likely to be increased much or frequently, because total kva. does not change so much with a given kw. change. The demand charge is favorably influenced from the purchaser's standpoint by high power factor.

In order to derive revenue from the excess investment required to furnish kw. to low-power-factor customers and to be fair with customers having a high power factor the rate structure often includes a clause which introduces penalty and bonus. For instance, the kw. used may be increased in the billing by 0.5 per cent for each 1 per cent that the power factor is below 85 per cent. Likewise the kw. hours will be decreased by 0.5 per cent each per cent that the power factor is above 85 per cent (up to unity). As an example, suppose two industrial plants each use 150,000 kw.-hr. in a given month. One has a power factor of 0.70 and is billed for 161,250 kw.-hr. The other plant has a 0.95 power factor and is billed for 142,500 kw.-hr. At a rate of 1½ cents per kw.-hr., the latter plant is billed $281.25 less for the month on energy charge alone. Power-factor clauses vary widely, but this one will illustrate the fact that good power factor pays on the energy part of the bill as well as on the demand part.

To summarize, the industrial purchaser is favored by high power factor in these ways:

1. By being able to increase loads without bringing on excessive voltage drop, because the reactance drop is negligible and resistance drop only need be considered.
2. Motor behavior in starting, running and under overloads is much improved, with consequent better production rate.
3. Lights are brighter and steadier.
4. Demand charges are less, because the ruling maximum is not likely to be so much over average demand.
5. Kilowatt-hour charges are less, since the penalty bonus rates favor high power factor.
6. A given quantity of power will be delivered to machines at a lower operating cost.

The control of power factor may be divided into two parts, the first part having to do with projected plants, additions or alterations, and the second part covering the control of power factor in existing plants.

When laying out a new project every effort should be made to use high-speed induction motors where it is possible to do so without excessive costs for speed-reducing connections to the driven load. It is equally essential to select motors so that they will be fully loaded as much of the time as possible. In making estimates for motor sizes it is well to bear in mind the "service factor," which specifies the amount of overload that can be carried continuously without dangerous heating. If the full load rating is considered as the maximum, "playing safe" will be certain to introduce many underloaded motors.

Synchronous motors have vigorously entered the field formerly exclusively held by induction motors, and general-purpose synchronous motors are able to handle almost any industrial load that has heretofore called for induction motors. Where it is found that the power factor as calculated is going to be less than, say, 0.9 it may be well to use some leading power-factor synchronous motors, a synchronous condenser, or a number of capacitors so distributed as to equalize the power factors of the various circuits. With these things well in mind, the copper required for power distribution as well as the cost for putting it in place will be materially reduced.

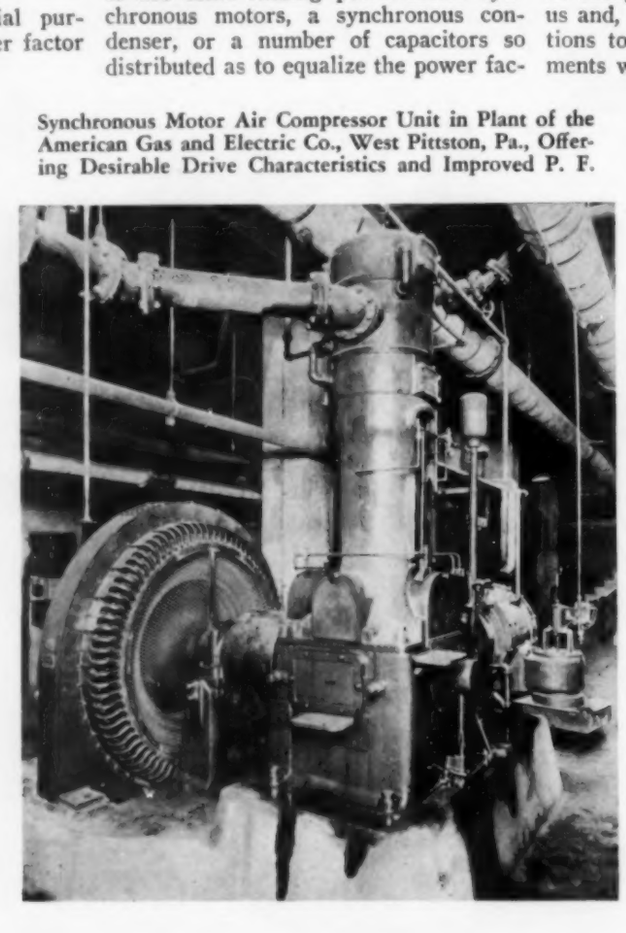
For existing plant conditions there are several expedients available for improving power factor. A preliminary check should be made to see if there are any induction motors very much underloaded. This can be done by checking the temperature by the hand. A half minute is as long as one can hold a hand on the stator of a fully loaded induction motor. Motors should be shifted around and oversize units disposed of so as to obtain a better distribution of loads. Where operating conditions are bad and the power-factor clause in a power contract justifies it, leading power-factor synchronous motors should be substituted for other motors, or a synchronous condenser or capacitors should be installed.

It is entirely possible to control automatically plant power factor under widely fluctuating conditions by means of any one of several electrical systems which have been devised for this purpose.

An exhaustive study of a given power-factor situation in order to compare many possible ways for improvement would ordinarily involve a great many computations along carefully conceived lines. These computations do not come as easily as they once did for most of us and, besides, there are many in positions to suggest power-factor improvements who are not familiar with "trig" tables or with substitute methods of calculating such matters. The graphic method, making use of a recently devised plotter, has the advantages of making the problem visible, avoiding errors, and suggesting expedients which never would occur to one through a maze of figures.

The power-factor plotter illustrated in Fig. 5 is very helpful in solving power-factor problems. It is obtainable from the General Electric Co., together with an explanatory folder giving ten practical problems and their solution.

Synchronous Motor Air Compressor Unit in Plant of the American Gas and Electric Co., West Pittston, Pa., Offering Desirable Drive Characteristics and Improved P. F.



ECONOMIES RESULT FROM IMPROVED LOAD REGULATION

By J. V. ALFRIEND, JR.
General Engineer
Westinghouse Electric & Mfg. Co.
East Pittsburgh, Pa.

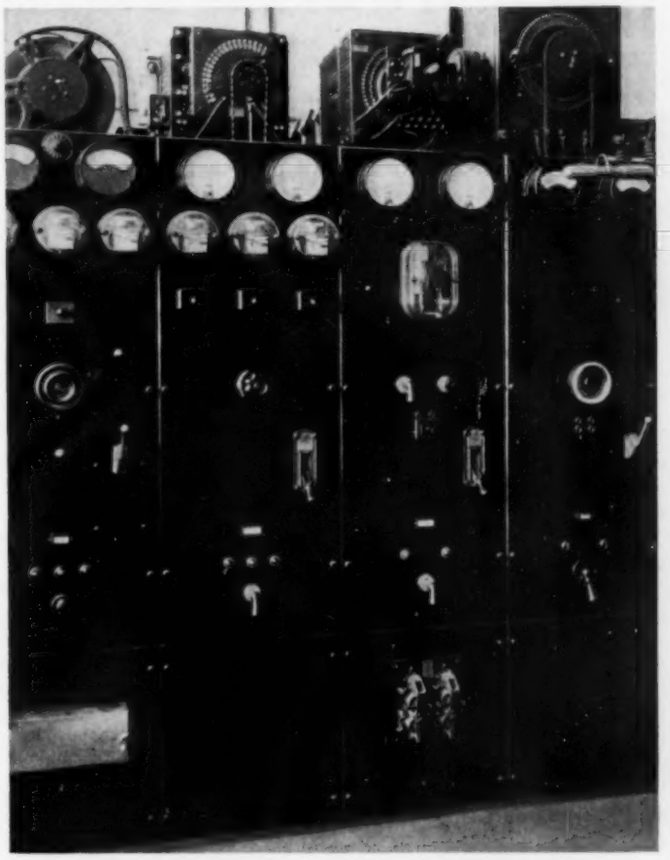
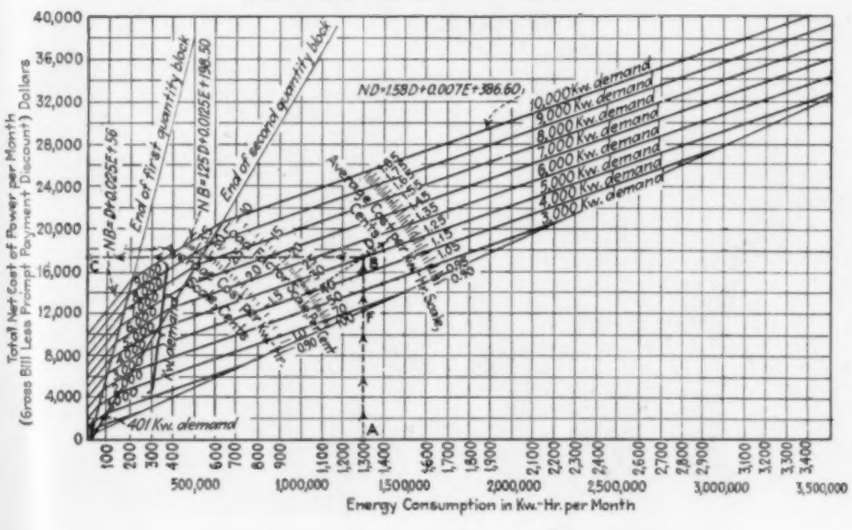


Fig. 2—Control Board Showing Constant Current Regulator

THE electrical load in process work, as in most other industries, is composed of a steady, unvarying base or firm load, on which is superimposed an erratic fluctuating peak load. The most noticeable difference between the usual industrial loads and a process load is the high percentage of its demand represented by base or firm load of the process industry. But in both this peak load is expensive from the standpoint of the consumer and undesirable at any reasonable price from the standpoint of the central station. In fact, peak-load kilowatt hours frequently represent a loss both to the purchaser and to the supplier of electric energy.

Two different types of plants will be analyzed in order to show the high cost of uncontrolled peak loads and what portion of this might be saved by the use of total plant-load regulating equipment connected either to limit or to regulate the power requirements. Details of a typical installation will be given, followed by other applications where this sort of equipment has been used for process control.

Fig. 1—Graphic Representation of Wholesale Power Costs



A certain steel mill, having a demand of 5,000 kw. and operating on a load factor of 36 per cent, consumed 1,300,000 kw.-hr. per month (W. M. Skinkle, *Iron and Steel Engineer*). In Fig. 1 this load has been plotted on a typical public-utility schedule, which indicates that the billing per month would be approximately $17,400 as shown by the intersection *B* of the vertical line from the 1,300,000 kw.-hr. and the sloped line for a demand of 5,000 kw. However, as shown by the intersection *F* of the vertical line and the sloped line for 100 per cent load factor, the net cost of this energy should be approximately $12,300. The difference between these two is the amount that the steel mill penalized itself for its inability to maintain 100 per cent load factor. This amounted to $5,100 per month.

Such a plant cannot control its demand so as to operate at 100 per cent load factor, but it can take steps to improve its load factor and greatly decrease its power billing. A study of the demand charts of this plant shows that certain large machines with inherently

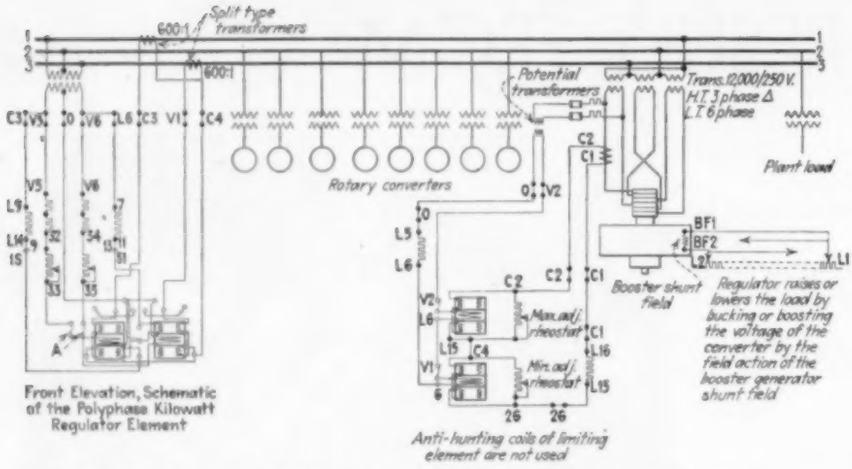

Split type transformers
600:1
Potential transformers
Trans. 12,000/250 V. H.T. 3 phase Δ L.T. 6 phase
Plant load
Rotary converters
BF1
BF2
Booster shunt field
Regulator raises or lowers the load by bucking or boosting the voltage of the converter by the field action of the booster generator shunt field
Max. adj. rheostat
Min. adj. rheostat
Front Elevation, Schematic of the Polyphase Kilowatt Regulator Element
Anti-hunting coils of limiting element are not used

Fig. 3—Schematic Diagram of Total Plant Load Regulating Equipment

intermittent operation were frequently used at the time when peaks occurred over the remainder of the plant. It was further found that these machines could be shut down for short periods of time with little or no warning.

A total plant-load regulator could be supplied to this system to disconnect these particular machines from the line automatically at times when the total kilowatt load reached a predetermined value and to reconnect the machines to the line after an interval of a few minutes, provided the peak is passed. This would bring the load factor up to 45 per cent and the demand down to 3,800 kw., thus reducing the monthly power bill by $2,000 for a few moments' inconvenience at no loss of production.

An electrolytic plant operating on a demand of approximately 4,500 kw. at 90 per cent load factor was paying for its power at a yearly rate based on its maximum 15-minute demand. This company discovered that it was using an average of 4,000 kw. and paying for 4,500 kw.-years at $29 per kilowatt-year. This represented a direct loss of $14,500 per year. That is, the extra billing of 500 kw.-years represented no production but cost $14,500.

Since the base load of this plant is an electrolytic load, it was realized that the expense could be saved if suitable regulating equipment was obtained. Fig. 4 shows the total plant-load regulating equipment that was installed in this plant and which has maintained the load at 4,000 kw. plus or minus 0.5 per cent for two years, thus realizing practically the complete limit of saving.

The diagram of this installation is shown in Fig. 3. It will be noted that the watt regulator measures the total incoming kilowatts. If this load should tend to increase above the predetermined amount, the "lower" contacts of the regulator would close and, through the reversing switches, would energize the motor of the motor-operated converter-field rheostat to decrease the voltage of the synchronous converter. Conversely, if the power should decrease, the "raise" contacts of the regulator would close and cause an increase in the converter voltage.

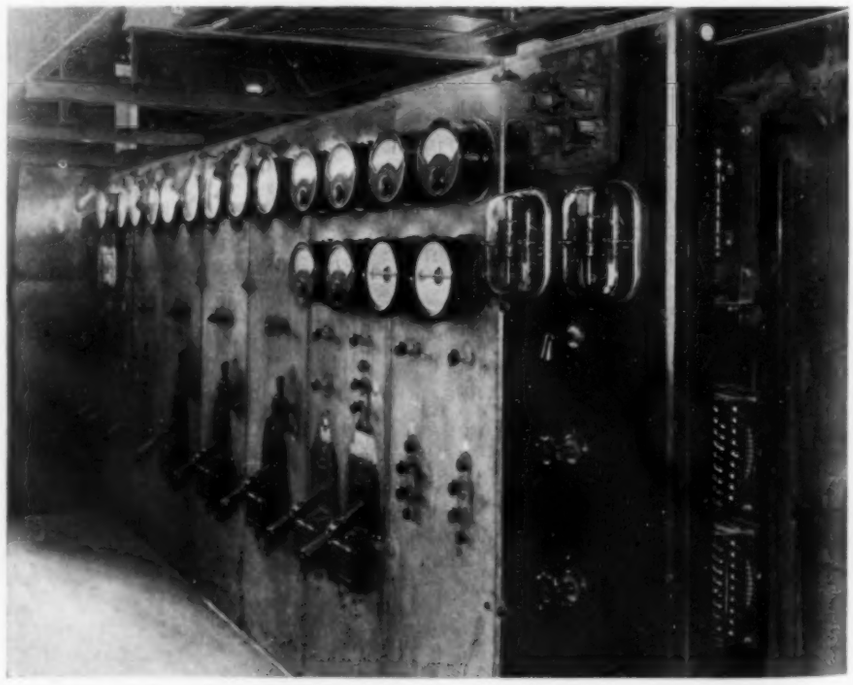
This synchronous converter is supplying power to an electrolytic load, and variation in the voltage will produce a variation in the load taken by the electrolytic cells and thus compensate for the variable load in the industrial section of the plant. This slight modification of the production rate does not decrease the total production, since the total number of kilowatt-hours consumed remains the same. Thus, this plant has realized the entire possible savings of $14,000 per year.

Prevention of hunting and holding of the regulated load close to the desired point is accomplished by energizing the field rheostat motor in a series of extremely short intervals when the power is close to the desired amount and energizing the motor continuously so long as the power deviates a relatively large amount from the desired quantity. Therefore, for a sudden large change in load the compensation is obtained at the maximum speed until the total load is almost right, at which time the speed of compensation is greatly reduced. As a result, the device does not cause overshooting.

The load regulator described consists of a watt element wound as a solenoid. It has the advantage of being inexpensive, yet of meeting most of the requirements for accuracy. A slightly more expensive and a more accurate device is shown in Fig. 5. This is the Kelvin balance regulator, the element of which is the same as that of a wattmeter. Therefore, this device has the same accuracy as the device which is measuring the power input to the plant from which the billing is calculated. Hunting is ingeniously prevented by the use of the two continuously rotating cams, *C1* and *C2*, which for small deviations of power permit energy to be supplied to the motor of the motor-operated rheostat only during a small proportion of the revolution of the cam. For large deviations of power, energy is supplied continuously to this motor. The arrangement can be easily understood by an examination of the cams and the contact member.

Similar equipment is used in the control of processes rather than in total plant-load regulation. A plant operating a 1,250-kw. motor-generator set found it necessary to maintain a very constant current in the electrolytic cells. This

Fig. 4—Installation of Total Plant Load Regulating Equipment



motor generator is shown in the foreground of Fig. 6, and the regulating equipment is shown on panel No. 3, reading from left to right of Fig. 2. An idea of the simplicity of this device is indicated by the fact that the panel also contains the control for the generator.

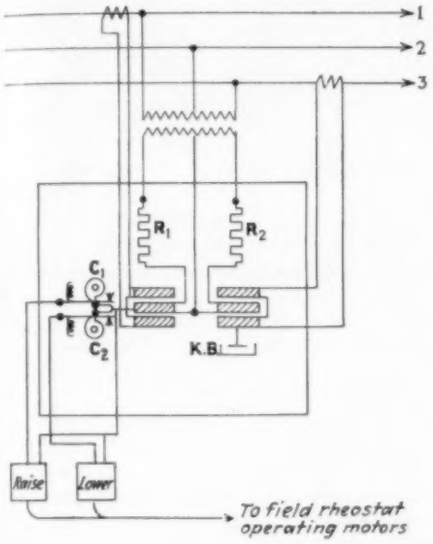


Fig. 5—Schematic Diagram of Kelvin Balance Load Regulator

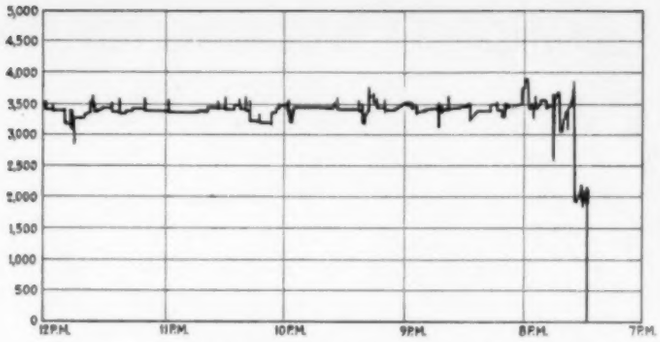


Fig. 7A—Graphic Chart of Current Drawn by Electrolytic Load Under Manual Control

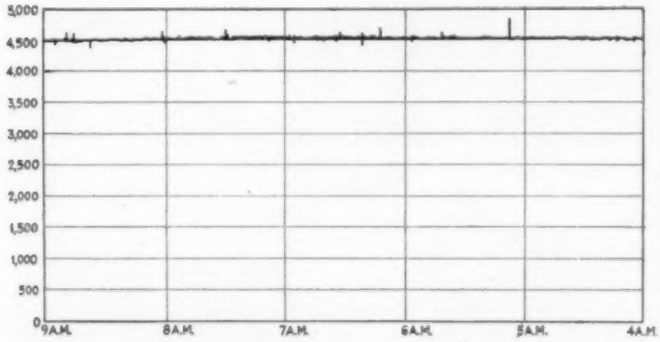


Fig. 7B—Graphic Chart of Current Drawn by Electrolytic Load With Constant Current Regulator

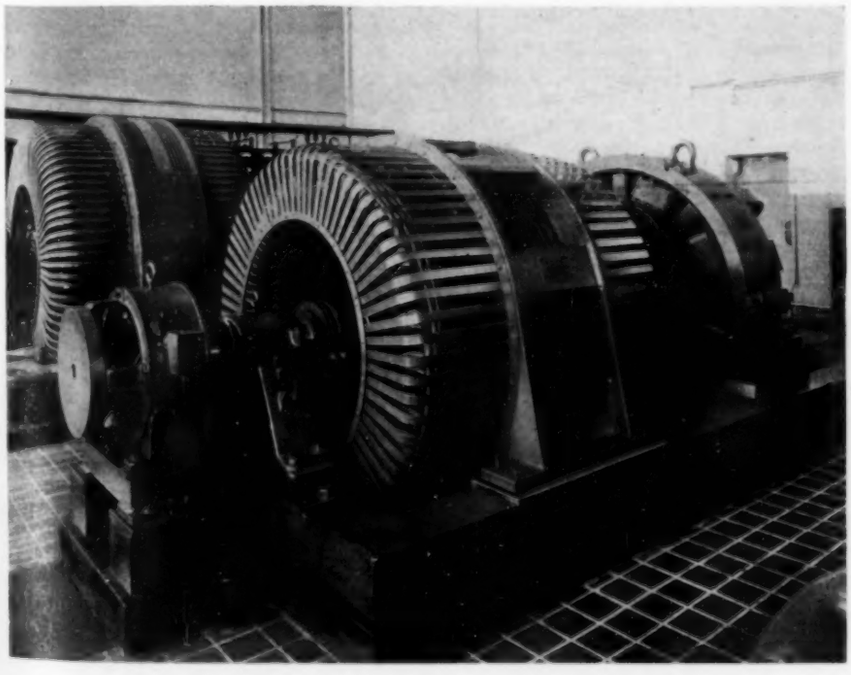
This regulator contains, instead of a watt element, a voltage element which measures the voltage drop across the interpole winding. This voltage is a true function of current and temperature in an installation operating over a narrow load range and over a period of 24 hours a day. Since both the regulator coil and the interpole winding are made of copper, the temperature coefficients of resistance of the two are similar. Thus, errors created by changing temperature conditions in the substation are negligible. Figs. 7A and 7B show the current chart drawn before and after the installation of the regulating equipment.

A different sort of device was installed by a steel mill whose contact-demand is controlled by the average of the three highest 15-minute demands in a month and whose billing-demand changes only in 500-kw. steps.

In this particular case a group of blooming, bar, and jobbing mills operate in tandem and constitute about half or more of the total electrical load, so that regulation of the rate of production in this continuous process can effectively control the total plant demand. Accordingly, there has been provided a round-chart type of demand meter with gearing arranged to make one revolution each 15-minute demand period. On the demand chart (actually a brass disk) is inscribed a curve corresponding to the calculated or contracted demand. This meter is located adjacent to the shear feeding brass to the jobbing mill and at all times is visible to the shear operator, which then controls the speed of the shear. In addition it regulates production all through the plant, so that the demand pointer is always kept under the curve drawn on the brass disk.

It has been shown that load-regulating equipment eliminates the costly power peaks, which is desirable alike to the central station and to the consumer, and that such regulation need not interfere with the operation of the plant. An analysis of his load chart and power contract should show any engineer in the process industry that his plant can realize the economies resulting from the improved load factor.

Fig. 6—1,250-Kw. Motor Generator Controlled by Constant Current Regulator



INDIRECT MEDIUMS FOR PROCESS HEATING

Indirect heating is a requirement of numerous processes where for many reasons, such as closeness of control and considerations of safety, cleanliness, ease of operation and improved working conditions, direct-flame heating cannot be practiced. Four articles covering the principal phases of indirect heat have been prepared by authorities and appear in the following pages. Electricity, as it is considered a primary energy source from the standpoint of the process, is omitted here but is covered in some detail on pages 223 to 225.

STEAM AND WATER FOR PROCESS HEATING

By ROBERT J. GORDON
Mechanical Engineer
Dover, N. J.

WATER in one of its three forms —ice, water, or steam—is more frequently used for industrial heat transfer than any other fluid. The first form, ice, is often applied in chemical plants where quick cooling is to be accomplished or sudden temperature rises are to be avoided, as in many organic syntheses. Water is almost universally employed as a heat absorbing medium in condensers and other coolers, and for internal combustion engines. As a refrigerating medium, it is becoming favorably known through its application in vacuum coolers and crystallizers and, more recently, in the form of a small, inexpensive flash refrigerating machine for air-conditioning.

As a heating medium, water suffers the same disadvantage as other liquids used for this purpose. Its rate of heat transmission through a surface separating it from a liquid receiving the heat is much lower than the rate for a condensing vapor, on account of high film resistance. This condition can be improved materially by increasing the velocity of the water over the surface, but only at greater pumping cost. Nevertheless, water is rarely used for industrial heating without some form of forced circulation, because gravity circulation requires excessive heat-transfer surface if any considerable quantity of heat is to be transmitted.

Water heating is useful for temperatures below 212 deg. F., since it can be controlled closely and can be conducted at atmospheric pressure. Steam heating in this range requires the use of sub-atmospheric steam pressure if a considerable temperature difference between the heating medium and the heat-receiving material must be avoided. In some cases, it is desired deliberately to reduce the rate of heat transfer, as in the drying of cellulose films and in certain dyeing operations. When such a result is desired, hot water under pressure is occasionally used for temperatures above 212 deg. F.

Process heating by steam for all temperatures up to, say, 350-400 deg., and occasionally higher, is almost universal. In every case, its pressure should be high enough to allow for a thermal head of 20 deg. or more. Within its useful temperature range, steam has the advantages of ready availability, small attendance, low operating cost, fairly low equipment cost, and ease of control. Even at higher pressures, it introduces no particular hazards. Since only its latent heat is generally used, constant condensing temperature is assured merely through control of the pressure.

Low Pressure Widely Applicable

In the majority of applications, steam can be used at low pressures, up to about 10 lb. gage, at which pressure its temperature is 239 deg. F. For higher temperatures, it is used at greater pressures, or superheated, or both. Superheated steam possesses the disadvantages that the greater part of its available heat is contained at the lower saturation temperature, and that the heat-transmission rate is lower even than the rate with water as the heating medium. Where superheated steam must be used to obtain high temperature at reasonable pressure, its utilization efficiency will necessarily be low, unless it can be used in a counterflow heat exchanger, as, for example, in apparatus similar to a benzol still. In this case its latent heat also is available.

Steam for heating may be used at boiler pressure; it may be obtained at decreased pressure by passing it through a reducing valve; it may be taken from the exhaust of an engine or turbine; or extracted from a bleeder turbine. Boiler steam is generally dry saturated or superheated; steam from a reducing valve, slightly superheated; exhaust steam, wet; and extracted steam, wet, dry or superheated, depending on the way the turbine is operated and on the bleeding pressure.

Whenever the excess temperature of superheat is not required, saturated steam will be preferable. Very wet steam throws an extra burden on the condensate return system, since its moisture content furnishes practically no useful heat. If the system has excess capacity, moisture probably will cause little trouble, if any. The disadvantages of superheat have already been mentioned. Hence, if the available steam has more than a few degrees of superheat or a few per cent of moisture, it will often by dried or desuperheated, as the case may be. Wet steam can be dried by passage through a moisture separator or a reducing valve, or into a flash chamber. It can be dried by compression with a steam-jet compressor. The superheat can be destroyed by spraying sufficient water into the steam to absorb the excess heat. The exhaust steam from reciprocating engines will generally contain oil which, if not removed in an oil separator, will coat the heating surfaces and reduce the heat transmission rate, as well as render the condensate unfit for direct return to the boiler.

Steam heat is applied in two ways. As "direct" steam, it is passed directly into the material which it both heats and agitates. In this way it gives up all of its heat, but it is lost to the boiler and also dilutes the product. For these reasons, it usually is uneconomical. Instead, steam is condensed in most cases so as to give up its latent heat at its saturation temperature and pressure within a jacket, coil, or bundle of tubes. The condensate is removed at a few degrees below saturation temperature by means of a trap, and is then returned, with its sensible heat, to the boiler, thus reducing the make-up water required. In every such application, particular attention must be paid to the proper operation of the trap, which, if it fail to operate promptly, may easily become the limiting factor in an otherwise well-designed installation.

DIPHENYL-TYPE COMPOUNDS FOR HIGH TEMPERATURE HEATING

By JOHN J. GREBE

Physicist, Dow Chemical Co.
Midland, Mich.

INDIRECT HEATING—that is, the use of fluids to convey heat from the energy source to the point of heat application—has developed rapidly in recent years. It is the purpose of the present paper to point out some of the principles of indirect heating, to show where it stands at present—with particular reference to the use of the diphenyl-type compounds—and, perhaps, to suggest some of the directions in which it is likely to go in the future.

Many processes do not lend themselves to heating by direct fire. Hence, it has been necessary to use relatively expensive and cumbersome methods of heat transfer in the past. Furthermore, until fairly recent years, the temperatures attainable by indirect methods have often been limited by expense or other considerations, and as a consequence, certain processes have been left undeveloped for want of suitable heat technology.

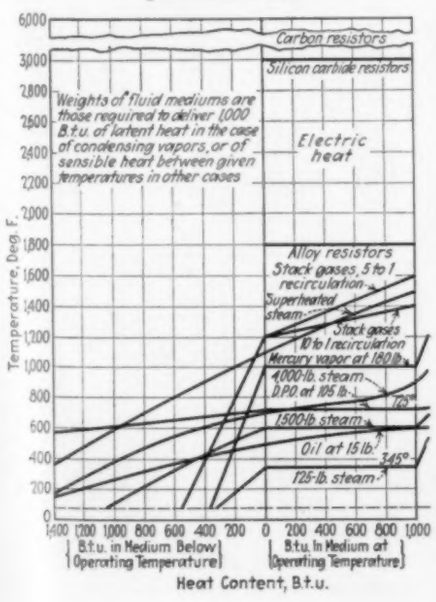
Some processes, for example, operate more efficiently at temperatures above those easily obtainable with steam: i.e., about 400 deg. F. If 500 deg. gives better results, then it is obvious that a method for attaining this temperature should be sought. Or if the distillation of a material requires a temperature of 600 deg., but exposure to this temperature for more than a very short time will injure the product, it is necessary to find a method of heating which will definitely limit the temperature and permit a high heat-transfer rate so that decomposition of the product will be kept at the minimum. A heat-transfer material suitable for this purpose can then be condensed at its necessarily high operating temperature and its heat below this point used to generate steam, say, at 350 lb., for the generation of power or for other process heating.

It is, of course, possible to attain relatively high temperatures with steam. Long before 1,500-lb. steam was generally known, we found its use advantageous for distilling high-boiling-point compounds at a condensing temperature of 600 deg. Thus, it was possible to operate without extremely high vacuum. In other work, we increased the availability of the heat in steam by using highly superheated steam at 4,000 lb., in order to allow for a considerable pressure drop and still have as much heat as possible available above 700 deg. F.

Steam under these conditions is somewhat similar in its properties to CO_2. Its specific heat immediately above the critical pressure and temperature is very high, so that a considerable quantity of heat can be transferred above 700 deg. F. without going to too high a temperature. This method, however, is applicable only where there is a definite need for the high pressure as well as the temperature, since other means of attaining high temperatures are cheaper, both from the viewpoint of equipment cost and of operating expense.

It is well known that for special purposes, steam at relatively low pressure has been superheated to as high as 1,400 deg. F. in order to use it as a heat carrier for various processes. However, even with these extreme conditions, it is obvious that there is a great difference between the heat in the products of combustion (available at a temperature upward of 2,000 deg. F.) and at the relatively low temperature at which it is absorbed in steam.

Fig. 1—Relative Heat Content in Heating Mediums Above and Below Temperature of Use



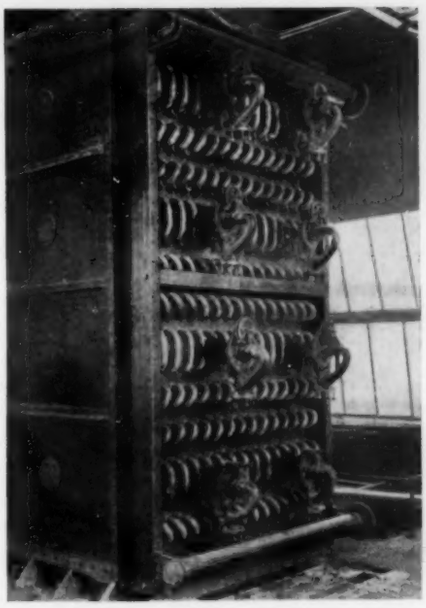


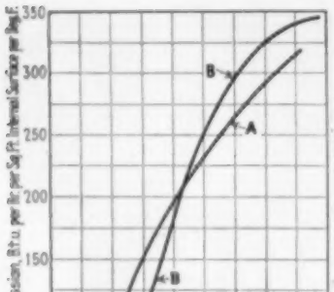
Fig. 2—Foster-Wheeler Economizer for Diphenyloxide Heating at Bremo

Various heat-transfer agents have been used to absorb heat at higher levels. The curves of Fig. 1 will give an idea of the approximate temperature ranges in which these various mediums are used. One of the most important of the high-temperature agents is mercury, which is being boiled at 900 to 1,000 deg. F. for the distillation of oil. Mercury, being an element, is absolutely stable, while even water decomposes at such temperatures in the presence of iron. Mercury is very fluid, it has a very high ratio of heat of vaporization to specific heat (which means that a high proportion of its heat can be released at the saturation temperature), and its high density is a great advantage in the heat transfer from the vapor and in returning condensate to the boiler.

On the other hand, its high specific gravity is a decided disadvantage in the construction and operation of the mercury boiler. It is believed, however, that by using a boiler filled with vapor passing through at a high velocity, in which the highly superheated vapor is desuperheated repeatedly with the boiler feed, many of the difficulties now encountered will be overcome. Under such conditions all the heat-absorbing surfaces of the mercury boiler would be swept with vapor to be superheated and would thus be free from water-hammer effects and excessively

Table I—Physical Properties of Diphenyloxide, Diphenyl, Water and Mercury

	Water	Mercury	Diphenyl-oxide	Diphenyl
Formula	H_2O	Hg	$(C_6H_5)_2O$	$(C_6H_5)_2$
Molecular weight	18	200	170.14	154.08
Specific gravity	1	13.6	1.083	1.165
Melting point, deg. F.	32	—38.2	80.6	156.6
Boiling point, deg. F.	212	674	496	491.5
Liquid volume, cc. per gm. mol	18	14.7	157	132.2
Sp. heat of liquid, cal. per gm. mol at 100 deg. C.	18	6.4	77	67.0
Heat of vaporization, cal. per gm. mol at b.p.	9,700	13,800	11,320	11,820
Sp. heat of vapor, cal. per gm. mol	10	6.4	79	.....
Ratio of sp. heats of vapor	1.28	1.66	1.046	.....
Cubical expansion coef. (0-100 deg. C.)	0.0005	0.00018	0.0008	.....
Heat of combustion, B.t.u. per lb.	.....	.....	14,000	17,440


Coefficient of Heat Transmission, B.t.u. per Hr. per Sq. Ft. Interval Surface per Deg. F.
Diphenyloxide Velocity, Feet per Sec.
A
B
D.P.O. temperatures, 60-280° F.
Unrestricted steam flow outside tube
Separating wall
Curve A, 1/8" std. steel pipe
Curve B, 3/8" copper tubing with 3/64" wall

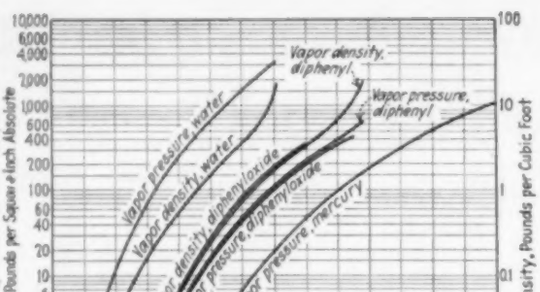


Fig. 3—Left, Over-all Heat-Transfer Coefficients Between Liquid Diphenyloxide and Condensing Steam

Fig. 4—Right, Vapor Density and Vapor Pressure for Diphenyl and Diphenyloxide in Comparison With Water and Mercury

high temperatures due to the increased pressure resulting from the hydrostatic head of the mercury.

For distillation of lubricating oils, mercury has been found very satisfactory according to the reports of the Sun Oil Co. Mercury heating gives a temperature sufficiently high to distill the oils without going to exceedingly high vacuum.

For still higher temperatures, numerous installations through all the industry, including our own chemical plant, have made use of the recirculation of stack gases with fair efficiency. Wherever the amount of heating surface required with the recirculation of stack gases is not prohibitive, and where there is no fire risk, this method is applied to good advantage. Blowers have been developed to handle red-hot stack gases for recirculating purposes.

Between the range of temperature readily covered with water and steam as a heat-transfer materials and that in which mercury must be used there is a range from approximately 400 to 750 deg. F. in which oils, diphenyloxide, and diphenyl are desirable. Oil heat, as used at low pressure in the Merrill process, has been satisfactorily used for years for temperatures up to about 600 deg. Covering this range and up to 750 deg. or somewhat higher, the diphenyl-type compounds come into the picture. These are stable, aromatic compounds, non-corrosive, non-poisonous, and capable of standing high temperatures for long periods of time without undue decomposition.

Of particular interest is the eutectic mixture of diphenyloxide and diphenyl, which has a melting point of 56 deg. F. when pure. As the boiling points of both are nearly the same, the concentration of the two compounds remains close to the eutectic mixture: 26 per cent diphenyl and 74 per cent diphenyloxide. This mixture does not freeze readily and is unlikely to plug up the return lines.

It is evident that each individual problem of indirect heating has its own solution. It is quite easy to select from these various heat-transfer methods the most economical one for any given case. For example: the preheating of air at the Bremo Station of the Virginia Public Service Corp. might conceivably be done with steam at, say, 1,200 lb. pressure, but this would have required heavy and expensive equipment. It would be rather odd to have an air-preheating system operating at a higher pressure than the boiler.

By the use of diphenyloxide, the operating pressure has been held down to 50 lb., which is ample to prevent the liquid from flashing into vapor at any point in the circulation system. It would hardly have been satisfactory to use latent heat for this heat transfer, since it is desirable to extract the heat countercurrently from the stack gases.

Usual power-plant practice in air preheating is to pass the air through an air heater inserted in the duct between the economizer and the stack. At Bremo, the design of boiler used made it desirable to eliminate a long air duct which would have increased the building volume materially. Furthermore,

Table II—Properties of Saturated Diphenyloxide Vapors*

Temperature, Deg. F.	Pressure: Lb. per Sq.In. Abs.	Pressure: Vacuum In. Hg	Heat Content B.t.u. per Pound: Liquid	Latent	Total	Density Lb. per Cu.Ft.: Liquid	Vapor
81	.....	.....	0	146	146	.....	.....
100	.....	.....	8	145	153	.....	.....
120	.....	.....	16	145	161	65.5	.....
140	.....	.....	24	144	168	64.9	.....
160	.....	.....	32	143	175	64.3	.....
180	.....	.....	41	142	183	63.7	.....
200	.....	.....	49	142	191	63.1	0.0012
220	.....	.....	59	141	200	62.5	0.0020
240	0.18	29.63	68	140	208	61.9	0.0034
260	0.29	29.41	78	139	217	61.3	0.0056
280	0.47	29.04	87	138	225	60.7	0.0080
300	0.72	28.54	97	137	234	60.1	0.012
320	1.1	27.76	108	136	244	59.4	0.019
340	1.6	26.74	118	134	252	58.9	0.026
360	2.2	25.53	129	133	262	58.3	0.036
380	3.0	23.90	140	131	271	57.8	0.050
400	4.0	21.90	151	129	280	57.2	0.068
420	5.3	19.20	163	127	290	56.7	0.090
440	7.0	15.8	154	125	299	56.2	0.12
460	9.1	11.5	186	123	309	55.7	0.16
480	11.7	6.2	199	121	320	55.2	0.21
496	14.7	0.0	208	120	328	54.8	0.26
		Lb. Gage					
500	15.3	0.6	211	119	330	54.7	0.28
520	18	3.3	224	117	341	53.9	0.36
540	23	8	237*	115	352	53.2	0.44
560	28	13	250	113	363	52.4	0.54
580	34	19	263	110	373	51.7	0.67
600	42	27	277	108	385	50.9	0.88
620	52	37	289	105	394	50.2	1.10
640	62	47	303	103	406	49.5	1.24
660	74	59	316	100	416	48.7	1.34
680	87	72	330	97	427	48.0	1.5
700	100	85	343	95	438	47.3	1.7
720	118	103	357	91	448	46.3	1.9
740	136	121	371	88	459	45.3	2.3
760	156	141	384	84	468	44.4	2.6
780	180	165	398	80	478	43.3	2.9
800	210	195	412	76	488	42.0	3.5
950	Critical Temperature.						

*Dow Chemical Co. (More complete tables available.)

Table III—Properties of Saturated Diphenyl Vapors*

Temperature, Deg. F.	Pressure: Lb. per Sq.In. Abs.	Pressure: Vacuum In. Hg	Heat Content B.t.u. per Pound: Liquid	Latent	Total	Density Lb. per Cu.Ft.: Liquid	Vapor
156.6	0.015	29.9	0.0	190.9	190.9	.....	.....
180	0.033	29.9	9.5	182.0	191.5	61.36	0.00058
200	0.060	29.8	17.7	175.0	192.7	60.85	0.00108
220	0.105	29.7	26.1	168.5	194.6	60.31	0.00190
240	0.177	29.6	34.8	163.5	198.3	59.75	0.00317
260	0.289	29.3	43.6	159.5	203.1	59.18	0.0053
280	0.457	29.0	52.6	156.5	209.1	58.62	0.0078
300	0.701	28.5	61.9	154.0	215.9	58.08	0.0117
320	1.050	27.8	71.4	152.0	223.4	57.52	0.0170
340	1.53	26.8	81.3	151.0	232.3	56.93	0.0239
360	2.18	25.5	91.4	149.5	240.9	56.36	0.0336
380	3.06	23.7	101.8	149.0	250.8	55.80	0.0460
400	4.20	21.4	112.6	148.0	260.6	55.24	0.0616
420	5.67	18.4	123.7	147.0	270.7	54.67	0.0804
440	7.54	14.6	135.1	145.0	280.1	54.09	0.1050
460	9.87	9.8	146.8	142.0	288.8	53.53	0.1410
480	12.80	4.0	158.8	138.5	297.3	52.93	0.1800
491.5	14.70	0.0	165.8	136.5	302.3	52.59	0.2100
		Lb. Gage					
500	16.3	1.6	171.0	135.0	306.0	52.32	0.236
520	20.6	5.9	183.5	131.0	314.5	51.69	0.310
540	25.7	11.0	196.1	127.5	323.6	51.05	0.395
560	31.7	17.0	208.9	124.5	333.4	50.41	0.495
580	38.8	24.1	221.8	121.0	342.8	49.73	0.615
600	47.0	32.3	234.8	117.0	351.8	49.04	0.750
620	56.6	41.9	248.0	114.0	362.0	48.35	0.910
640	67.5	52.8	261.2	111.0	372.2	47.64	1.085
660	80.0	65.3	274.6	108.5	383.1	46.95	1.285
680	94.2	79.5	288.0	105.5	393.5	46.20	1.510
700	110.1	95.4	301.5	103.0	404.5	45.38	1.730
720	128.0	113.3	315.0	100.5	415.5	44.57	1.965
740	148.0	133.3	328.6	98.0	426.6	43.72	2.245
760	169.9	155.2	342.2	96.0	438.2	42.82	2.565
780	194.4	179.7	355.9	94.0	449.9	41.87	2.945
800	221.8	207.1	369.6	91.5	461.1	40.89	3.355
820	251.0	236.3	383.3	88.5	471.8	39.84	3.825
860	318.9	304.2	410.8	80.0	490.8	37.48	5.040
900	399.7	385.0	438.4	67.5	505.9	34.58	6.850
940	495.3	480.6	466.0	47.0	513.0	29.93	10.070
980	607.0	592.3	493.7	0.0	493.7	19.60	19.600

*Federal Phosphorus Co. (More complete tables available.)

the duct would have also given rise to considerable heat loss. The simplicity of the single-pass boiler used would have been sacrificed unless the building height had been increased. Instead of an air heater, then, a diphenyloxide economizer was installed, and this was connected by relatively small piping to the air heater placed near the point of air use. Further advantages of the diphenyloxide system included high efficiency, easy controllability, and a higher heat-transfer rate than could have been obtained between the flue gas and the air.

On the other hand, in an installation such as the one we are now putting in at our plant, which is intended for distillation of high-boiling-point organic compounds, it is most advantageous to use the latent heat of the diphenyloxide, thus attaining a definite temperature under definite pressure conditions. The condensate is returned to the boiler at a rather high temperature and re-evaporated.

A great many installations have been made in the past six years in which diphenyloxide and its mixtures have been used for transferring heat to small stills. Many of these stills use electric heat for heating the diphenyloxide, the vapor rising and enveloping the heat-transfer surface, while the condensate returns by gravity. Some of this equipment has been in operation continuously for more than three years.

The great advantage in using this method, even though it might be possible to buy a still electrically heated in zones, is that the temperature on the heated surface is uniform and the danger of overheating is eliminated. Another advantage is that in many reactions there is first a heating period and then a period during which heat is evolved. In these cases it is very easy to maintain the temperature and remove the evolved heat merely by controlling pressure.

Another particularly interesting application is the case in which a large cylindrical reactor is to be maintained at 600 deg. F. Heat is evolved at one end of the reactor and the problem is to remove it in order to keep the temperature down, while at the other end heat must be applied. The use of a jacket partially filled with high boiling fluid makes it possible to transfer the heat from one end to the other and, at the same time, to maintain the temperature within close limits.

One instance which recently came to our attention required that heat be transferred to a very corrosive material through a rather expensive glass surface which would not withstand much pressure. To do this with steam would have required very extensive apparatus in order to furnish enough surface for the low heat transfer available. Diphenyloxide permitted a total heat transfer of 10,000 B.t.u. per square foot per hour because it was possible to raise the temperature on the heated surface from 230 to 500 deg. F. at the same pressure. This made the entire operation practical.

In fact, in all this, the simplicity of the methods of application is apparent. They merely require the substitution of a high-boiling-point liquid for water in systems that are already well known.

Construction of a diphenyloxide boiler and piping follows in general the accepted practice for high-temperature work. All joints should be welded, not caulked or riveted, and care should be taken to insure a perfect weld, as nearly as possible free from porosity. Threaded pipe joints made of extra heavy pipe and forged-steel fittings have been found to hold at temperatures up to 800 deg. F. on repeated heating and cooling, provided that the thread is perfect and the pipe size not larger than ½ in. For piping of larger size, joints should always be welded, and forged-steel fittings should be used and welded to the pipe. Packing should be avoided as far as possible, since few such materials will long withstand the higher temperatures. Where they can be used, flexible metal gaskets have served very well. Where other packing is necessary, a very dense asbestos material coated with graphite has proved to be the best. No composition-packed joint has been found to be absolutely tight.

Equipment suitable for utilizing diphenyloxide vapor will, in general, be similar to that designed to operate with steam. The heating fluid will ordinarily be confined within a jacket surrounding the reaction vessel, or it may be passed through coils or pipes located within the apparatus and connected to suitable drums or "headers" for distributing the hot vapors and collecting the condensate. All forms of construction, of course, must be designed and built to withstand the higher temperatures and the expansion and contraction accompanying variations between room temperature and about 700 deg. F.

In many manufacturing processes it is necessary or desirable to use enamel-coated steel reaction vessels, stills, and the like in order to avoid contamination or discoloration of the product. Such apparatus usually is obtainable with jackets suitable for, and restricted to, a maximum of 35 lb. gage pressure, corresponding to a water-vapor temperature of about 280 deg. F. It is frequently desired to operate such equipment at higher temperatures, and in that event diphenyloxide, diphenyl, or oil may be used as the heating medium without exceeding the pressure that the equipment will withstand. By this means the range of usefulness of enameled-steel apparatus and similar thin-walled equipment may be greatly extended.

In the plant layout it is advisable, wherever possible, to locate the vapor-using equipment at a point higher than the upper boiler drum to provide for the return of the condensate to the boiler by gravity.

Careful estimates which we have made for boilers furnishing more than 1,000,000 B.t.u. per hour show that the cost of diphenyloxide or diphenyl vapor is not more than twice that of the cost of steam under similar conditions of fuel and boiler capacity.

As an illustration, the operating cost of a unit designed to deliver 10,000,000 B.t.u. per hour is reliably estimated to be within $6 per hour, and the cost of equipment exclusive of buildings, $20,000. Based on a steam cost of $0.35 per 1,000 lb., at 350-lb. pressure, which is roughly equivalent to $3.50 for 10,000,000 B.t.u., the cost of the heat in diphenyloxide vapor is about 70 per cent higher. However, it is delivered at a temperature of about 700 deg. F. instead of 440 deg. for the steam, giving 72 per

Fig. 6—Typical Installation for Heating by Circulation of Diphenyloxide Liquid

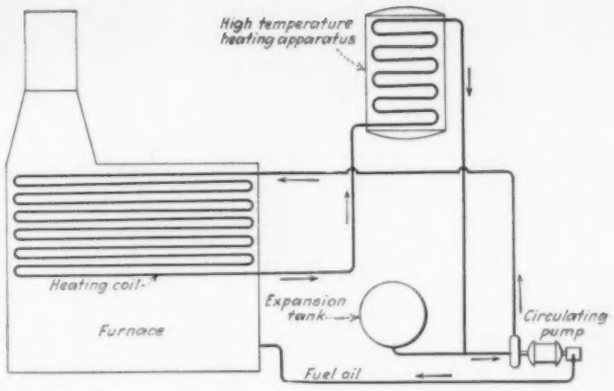
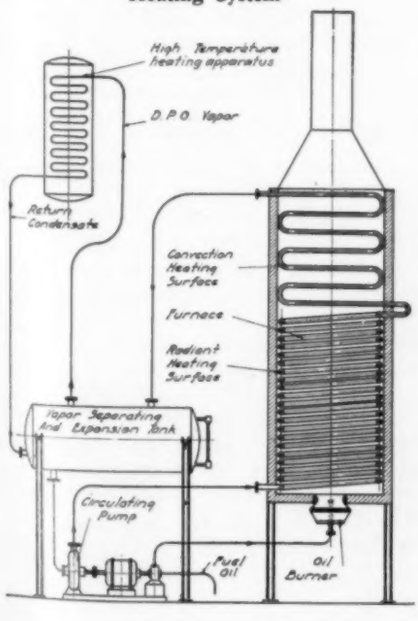


Fig. 5—Typical Diphenyloxide Vapor Heating System



cent more available temperature head. This relation obviously does not hold for very large installations where the advantage of high availability is obtained for less cost.

Batch processes must be used in many industries because of difficulties in maintaining accurately controlled temperature conditions and close analyses where the material is passing through a continuous process. Use of indirect heating methods would permit more accurate control of the main variables in continuous processes and hold exactly the right temperature at every stage. It seems likely that the great increase in the quantity of product for a given capital investment and the efficiency with which raw material is converted in continuous processes will favor further applications of indirect temperature control.

It is easy to see, for example, how continuous processing and the elimination of a lot of inventory might reduce fire hazard, give a uniform production and increase purity and quality in the paint and varnish industry. The new resins recently introduced have changed the industry sufficiently to make the development of new equipment and apparatus more likely.

Use of diphenyloxide, diphenyl, and of oils having an even higher thermal stability with a much higher boiling point, has been suggested for heat storage in power plants. It is well known that rapid load fluctuations are a source of considerable extra expense and operating difficulty in utility power generation. The use of these high-boiling-point fluids permits heat storage at low pressure and a temperature sufficiently high not only to preheat water for the boilers but also for generating superheated steam at the station pressure for standard turbines.

Heat may be extracted in this manner in an economizer and then stored in a tank containing considerable iron for increasing the heat capacity per unit volume. The fluid may be used for air preheating, as at Bremo, and also for controlling the superheat and the reheat temperatures for the steam going to the turbines. When a higher load comes on, the stored heat can be used to increase the preheating of the feed water so that more steam is produced for a time with the same fuel consumption. With further increases in load, and with the same absorption of heat in the boiler, additional fuel can be fed into the furnaces, the preheating of the air can be progressively decreased, and the heat in the high-boiling fluid can be used for further preheating and evaporation of part of the boiler feed water as it comes from the bleeder heaters.

Finally, when the load on the station has increased still further, heat from storage may be used to take the place of the bleeder heaters so that additional capacity can be obtained from the same turbines without exceeding the steam capacity of the boilers.

MERCURY VAPOR IN INDUSTRIAL HEAT TRANSFER

By CROSBY FIELD
Consultant
Babcock & Wilcox Co.
New York City

CONDENSING OF VAPORS is the preferred method of transferring heat, when the problem is considered from the viewpoint of the piece of chemical-plant equipment being heated. The high rate of heat transfer so obtained per unit of surface, 10 or more times that transferable from a liquid, and 100 times that transferable from a gas, gives a comparatively small jacket or heating coil, and permits close control of temperatures. It also facilitates the operation of a number of pieces of apparatus from one central heating plant or boiler. The reader will recall that the above comparison of heat-transfer rates refers only to that across the heating medium "film." The material being heated may have characteristics tending to equalize or otherwise unbalance the comparative heat-transfer rates when considered from the viewpoint of the over-all transfer of heat; that is, from the heating medium, through all "films" and other conducting materials, to the material being heated.

Primary sources of heat, covering the entire range of industrial temperature requirements, include: (1) Direct flame; (2) hot gases; (3) steam; (4) superheated steam; (5) circulating water at low or high pressure; (6) circulating oil; (7) molten baths; (8) electricity; (9) mercury vapor; (10) various special vapors; (11) sand and water baths.

A detailed discussion of the various heating mediums was given by the author some years previously (*Chem. & Met.*, **30**, 1924, pp. 987-91). The principal objections to using direct flame, hot gases, and superheated steam lie in the high heating-medium temperatures required and the consequent difficulty of control and almost certain local overheating. Circulating water and steam are excellent in a narrow temperature range, but as the needed temperatures rise, soon pressure-withstanding apparatus is required that is costly and difficult to design and to build. Circulating oil has been used to a considerable extent, particularly within the temperature range from 160 deg. C. (320 deg. F.) to 240 deg. C. (464 deg. F.). It is, of course, a flammable liquid, requiring pumps, and subject to wide variations in physical characteristics with temperature. In its deterioration in service, the substances formed may foul the heat-transfer surfaces. Baths of molten materials, always uncertain and sluggish, are rarely used in chemical-plant practice, and electricity, where it is not ruled out by cost, is not so certain in its uniformity of control as is a vapor. Among the special substances, diphenyl and diphenyloxide have been seriously exploited recently, but they are still new and, in comparison with mercury vapor, are comparatively untried.

Steady progress since the author's last summary in *Chem. & Met. (loc. cit.)* has been made in the development and application of mercury vapor as an industrial heat-transfer medium, particularly in its use in heating, cooling, and temperature controlling systems in connection with chemical processes. Nothing radically new in principle has been evolved since that time, but many improvements in the materials of construction of the necessary equipment have been made; the size and scope of individual units have been much increased; and, best of all, a sufficient number of people have been trained by experience so that the element of the unknown in design, construction, and operation has been largely eliminated. Operating data over many years in large-sized installations are now available on which to base the design of new plants.

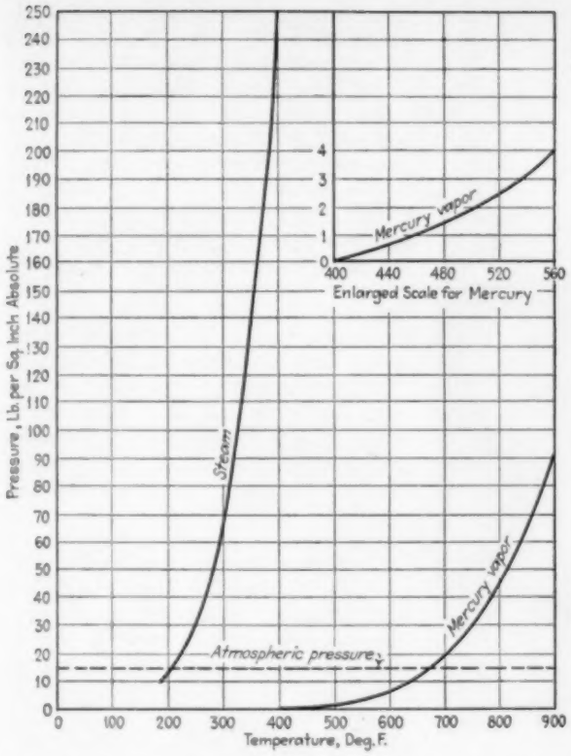
In addition to the ordinary system employed to supply heat to chemical reactions at higher temperatures, mercury-vapor heating has been applied in the petroleum industry on a large scale in lubricating-oil distillation. There are also several large installations employing vaporization of liquid mercury as a cooling agent for catalytic exothermic reactions at high temperatures.

Operating Advantages of Mercury

Mercury as a heat-transfer medium has the following advantages:

1. As it is an element it does not dissociate or form any compounds by recombination of its atoms, as do complex substances. There is, consequently, no fouling of the heat-transfer surfaces, nor any change in quantity of the heat-transfer medium (mercury) in the system.

2. Mercury freezes at — 39 deg. C. (— 38 deg. F.), so for practically all operations there is no danger of its solidifying, even when the plant has been shut down. Hence, there is no need for thawing accessories and no freezing hazard to combat in the major equipment.



Comparison of Boiling Points of Mercury and Water

Mercury vapor systems may now be said to operate as easily as steam systems. In comparison with other methods of heat transfer at high temperatures, mercury offers the great advantage that there are no pumps needed. As noted above, under any normal operating conditions the mercury cannot solidify. It is very quick in action, and the heat transfer rates are extremely high, giving values in every way comparable with steam under similar conditions. There is no loss by oxidation or decomposition, and heat-transfer constants of the system remain the same, year in and year out. Very high velocities, also comparable with steam, are permissible in the vapor system and, consequently, small piping may be used.

3. Mercury vapor is dense, as a consequence of which pipes may be small and designed for low pressures. This also reduces the size of the equipment and the inclosing buildings.

4. The high specific gravity of the liquid renders pumping unnecessary and gravity returns are possible under most operating conditions found in chemical plants.

5. Mercury and its vapor are nonflammable and, therefore, do not introduce fire hazards.

6. The most common and cheapest construction material, steel, is not affected by contact with either mercury or its vapors.

7. Mercury-vapor-proof welds are readily obtainable.

8. The latent heat of vaporization of mercury varies from 128 B.t.u. per pound at 0.4 lb. per square inch absolute pressure to 118 B.t.u. at 73 lb. per square inch absolute pressure.

From these facts, it is easy to see that mercury-vapor heating, cooling, and temperature-control systems may readily be designed and built to provide for effective temperature control, elimination of hazard, and any required temperature up to 500 deg. C. (932 deg. F.). Other advantages include low operating cost, low maintenance cost, immediate "pick up" from one temperature to another, small building space, high heat transfer, high effective temperature drop available, and simple attachment to any type of apparatus. Mercury systems can use any source of heat, such as oil, gas, coal or electricity, without the possibility of overheating. They offer quick addition and abstraction of heat, simplicity of operation, and require little or no attention.

Boiler Performance Efficient

The mercury boiler itself has been developed to a good degree of efficiency: for example, the more modern, oil-fired, boilers of moderate size have an over-all furnace and boiler efficiency of about 67 per cent, and are designed to operate on a flue temperature of about 600 deg. F. Most boilers are now put in with air heaters and give an over-all efficiency of about 75 per cent. In larger sizes these efficiencies may be somewhat better.

The quantity of mercury required in the entire heating system depends on its size, the general layout, the pressures and velocities permissible, and the rapidity of heating, cooling, or temperature control required. Large systems operate with as little as 1 lb. of mercury in the system, including that in the boiler, for each 1,000 B.t.u. per hour delivered to the substance being heated. Smaller systems, or those requiring more accurate temperature control, or lower ranges, may require two or more times this quantity of mercury per M B.t.u. per hour.

Extension of the lower limits of practical use of mercury vapor now brings it into direct competition with steam at temperatures as low as 150 deg. C. (303 deg. F.), particularly where the equipment is large, and the expense of a shell designed to withstand jacketed steam at higher pressures (above 56 lb. per square inch) is consequently great. The jacket pressure required with mercury vapor for this temperature is 3.13 mm. (0.06 lb. per square inch).

Special alloy steels have permitted the extension of the upper temperature limit to that of saturated mercury vapor at 130 lb. per square inch absolute (940 deg. F.). Small boilers have been operated at over 200 lb. per square inch absolute (1,010 deg. F.). Valves and other accessory parts for operation under these extreme conditions have been perfected.

Before operating any mercury vapor system, it is now the practice to evacuate it to the lowest obtainable vacuum, for which the welding must be so excellent that there is no measurable leakage, even over several months of operation. The best practice calls for evacuation to 0.2 mm. absolute pressure. This low pressure not only makes certain that the system will be absolutely tight but also renders it perfectly safe and economical to operate on high vacuum, thus reducing the lower limit of operating temperatures in the normal steam range.

Another improvement has been the development of a very simple valve, especially designed to operate under vacuum, and on low pressures above atmospheric. It is based on the principle of a U-tube filled with liquid mercury. By operating this valve automatically by means of thermocouples or other temperature-actuated devices, it is now possible to have a boiler operating at fairly high absolute pressures, nearly atmospheric, and still have the jackets or coils of the heat-transfer apparatus operate under the extremely low pressures required for the low temperatures desired. This also affords the opportunity to use one boiler system for a number of reactors, each operating under a different set of temperature conditions.

The principal advantage of this method of valving is that smaller boilers and mains can be used at the higher pressures, as the increase in volume at low pressures is very large, making the size of the boiler and of the distribution system almost prohibitive.

The objection has been raised that mercury vapor is toxic, and yet the authentic cases of mercury-vapor poisoning, due to its use in large quantities over many years in heating systems, are so infrequent that we can find practically no record. On the other hand, mercury vapor is not flammable and, in case of leakage from a system under pressure, condenses so rapidly that it can fall in a spray without injuring anybody it does not directly strike. Furthermore, by far the greatest use for mercury vapor in most chemical operations is in the temperature ranges which require a vacuum. There has been no case recorded of a vacuum system producing any toxic conditions with the operating force.

CIRCULATING HOT OIL FOR INDUSTRIAL HEATING

By A. B. McKECHNIE
Engineering Department
Parks-Cramer Co.
Fitchburg, Mass.

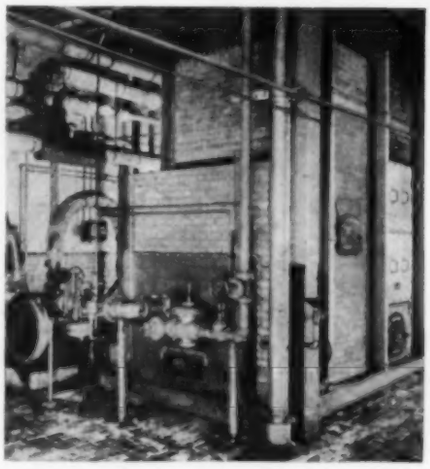
INDUSTRIAL HEATING by hot oil circulation finds its principal application in processes requiring carefully controlled temperatures somewhat beyond the range obtained with steam at ordinary working pressures. In the chemical engineering field, temperatures from 350 to 600 deg. F. are often maintained most satisfactorily and economically by the use of an oil system. To accomplish the same heating with saturated steam would require pressures up to 1,500 lb.

Some of the industrial operations in which heating by hot oil circulation has been successfully applied include the processing of asphalt, waxes and resins of high melting points, the deodorizing and refining of vegetable oils and compounds, the manufacture of dextrine from starch, and the many processes of organic synthesis required in the dye and coal tar, plastics, rubber, photographic and pharmaceutical industries.

In fundamental principle, a hot oil circulating system is like a hot-water system, but because of the markedly different characteristics of oil as compared with water, it presents a number of engineering problems of design and operation. Some of the basic requirements to be met in any successful process of indirect heating include the following:

1. The temperature of the heating medium must exceed by a considerable margin the maximum temperature of the material to be heated. In other words, there must be an ample thermal head or temperature difference.

2. The heating medium must be under sufficiently low pressure to allow for the safe use of the various types of apparatus necessary for efficient operation at the point where the heat is utilized.



Typical Merrill Process Oil Heater

3. The heating medium must have ample heating-carrying capacity and must give up its heat readily. In other words, it must permit a high rate of heat transfer in order to reduce the amount of heat transfer surface as well as the time required for performing the heating operation.

4. As far as possible, the heating equipment must be free from fire hazards, risk of explosion, or danger due to excessive pressure.

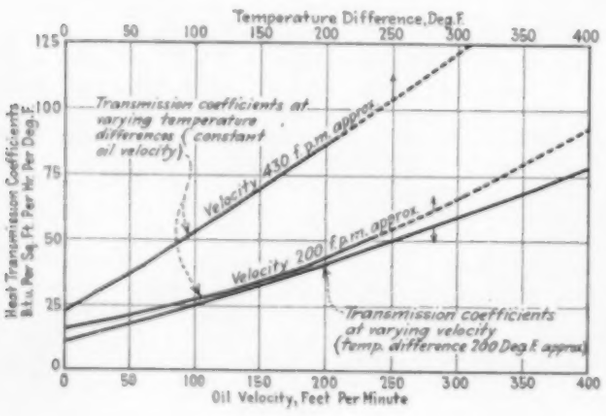
5. The heating equipment must have a high over-all thermal efficiency in utilizing the primary source of heat, whether it be gas, oil, or coal.

Hot oil circulation as now carried on in well-designed installations is able to meet all of these requirements. In the first place, the hot oil may be circulated at temperatures as high as 600 deg. F. and as the maximum temperature of the materials heated usually will be between 300 and 550 deg. F., there always is sufficient temperature difference to allow for a rapid rate of heat transfer. The only pressure on a well-designed system is the static head plus the slight pressure necessary to overcome friction in the circulating line. Accordingly, oil circulation is applicable to practically any type of jacketed vessel or coil. At the point where the heat is utilized, the pressure will rarely exceed 20 lb. It is ordinarily not more than 10 or 12 lb. at the heater outlet and only half of this on the tank jackets or heating coils.

The oil heater or absorber, as it is often called, is the only point in the system at which any flame or incandescent surface is involved and it may be located at any reasonable distance from the point of application of the process heating, thereby eliminating any risk of explosion or fire hazard from the process itself. Furthermore, the heat absorber usually is placed in a fireproof room entirely isolated from the apparatus where the heat is applied. Finally, the furnace design may be arranged to suit any kind of fuel used and thereby obtain the advantages of a high furnace efficiency. This efficiency compares favorably with the best results found in steam boiler practice for units of equivalent size—that is, up to 2,800,000 B.t.u. per hour—and greatly exceeds the actual efficiency which usually exists under direct-firing methods.

Heat transfer characteristics of oil heating have been determined in tests both at constant velocity and at constant temperature difference. Coefficients plotted on the chart at the left may be used in predicting B.t.u. transmission under various conditions of service.

In concluding this brief summary, I would like to call attention to the fact that many of the attempts made to use oil heating in process industry applications have been unsuccessful primarily because the user has tried to design his own apparatus, either by the assembly of standard parts or by the use of commercial equipment originally designed for an entirely different purpose. With few exceptions such equipment does not prove satisfactory, the difficulty perhaps not being due to any fault in the general principle of design but rather to a lack of experience in a new field where the details are not properly arranged or proportioned. The material and quantity to be heated, final temperature, design of tank or kettle, process time, heating surface, heat transfer coefficients, and many other factors compel the most careful investigation. Each important application of oil heating should be handled by an expert capable of properly grasping the detailed requirements and making recommendations to insure a successful working installation of high efficiency and long life.



Heat Transfer Coefficients for Circulating Oil

Transmission rates through extra heavy steel pipe to boiling water for constant temperature differential and for constant oil velocity

HEAT INSULATION DEVELOPED FOR EVERY PURPOSE

By B. TOWNSHEND and E. R. WILLIAMS

Respectively Manager and Insulation Engineer
Johns-Manville Research Laboratories
Manville, N. J.

UNTIL after the middle of the last century, very little thought was given to insulations, their effectiveness and their development; but with increasing steam pressures, increased temperatures, and increased cost of fuel, it became desirable to prevent the waste of heat from the uninsulated bare surfaces.

In 1841, Peclet published his pioneering experiments in the field of measuring the "conductibility" of metals. The formulas which he evolved applied equally as well to the heat flow through insulating materials; and, therefore, with a method at hand of actually measuring this property of a material and with the rapid strides being made in the industrial and mechanical fields, the development of insulating materials assumed its rightful place in ever increasing proportions.

Starting in the early 70's, came the first commercial development of pipe covering in the form of plastic cements made from clay and asbestos fiber; next lime was mixed with sawdust, wool waste, and paper pulp, with a flour adhesive, or anything that would stay in place on a pipe and could be troweled on. Now insulation development in both pipe covering and block form has passed through the stages of generalities where one type of material was used for all purposes, to the stage of specialties, where each rather narrow range of temperatures and each rather limiting condition of service has its own special material or materials, scientifically designed to give maximum efficiency and service.

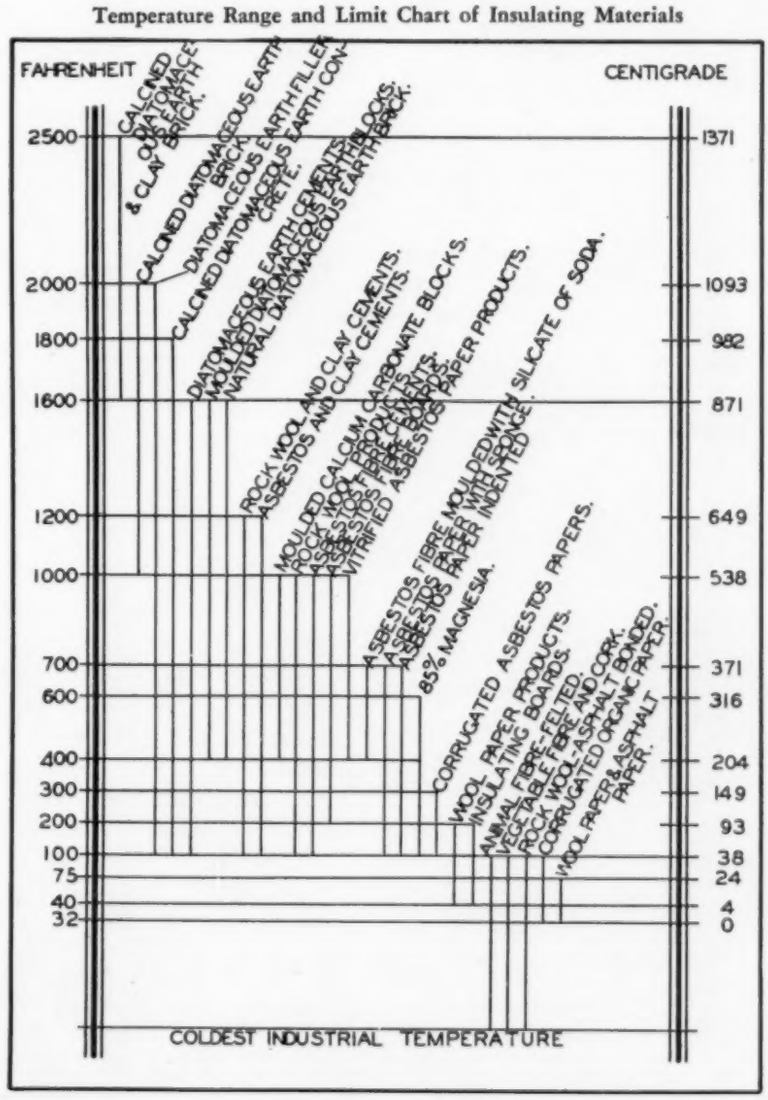
In the late 70's, the first coverings of definite thickness were developed and took the form of corrugated asbestos paper wrapped up to form an air-cell type of covering.

In 1885, the now well-known 85 per cent magnesia was discovered, and it replaced the air-cell type of covering for all but the low-pressure steam lines. This material showed greater effectiveness in preventing heat losses and became the general all-around insulation. However, for cases of severe service, where, due to excessive vibration or where subject to external damage, this magnesia proved unsuitable, a molded material composed of asbestos fibers and water glass was developed. As this latter material was less efficient than magnesia as an insulator, it became desirable to find a material as effective as magnesia and as durable as the molded fiber material.

Laminated asbestos felts were next fabricated into insulations, the laminations at first being wired together and later cemented by bands of sodium silicate. Various methods were used to improve the effectiveness of this laminated material, the most successful being the imbedding of particles of cut sponge in the asbestos felts. Indenting the asbestos felts to form air pockets became another common practice.

In 1895, pure corkboard and pure

Temperature Range and Limit Chart of Insulating Materials



cork-pipe covering were developed for refrigeration purposes. This material contained no foreign bonding agents, since the natural gums sufficed for the purpose upon heat-treatment of the material.

Fifteen years later, blown argillaceous limestone was mixed with asphalt and formed into a synthetic corklike insulation for refrigeration work.

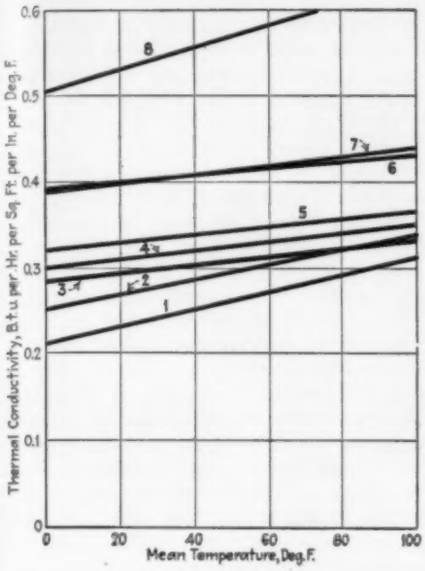
When superheated steam came into general use and ordinary steam temperatures crept above 550 deg. F., it was discovered that magnesia was not the correct insulating material, on account of its tendency to calcine and crack. Consequently, by 1925 there had been developed a series of compositions employing diatomaceous earth as a base. Molded materials, consisting principally of lime for temperatures of 1,000 deg. F. to 1,200 deg. F. and of diatomaceous earth for temperatures up to 1,600 deg. F., came into use. For temperatures above 1,600 deg. F. to 2,500 deg. F., diatomaceous earth and clay were burned together in brick form, and this combination affords satisfactory insulation for this service.

Naturally, while each of the above mentioned insulations was being developed, there were also being developed many slight variations from the generally approved product, mainly for some special condition, such as limited service, price, application, and appearance. Therefore, there are available for the lower temperatures: vegetable cork; mineral wool blown from mineral slags and rock wool blown from argillaceous limestone, both bonded with asphalt; kapok fiber; laminated wool-felt paper; insulating boards made from bagasse fibers, licorice roots, various kinds of shredded lumbers, and wheat straw; felted cattle hair; corrugated kraft paper; and the most recent, aluminum foil. For the medium temperatures we have corrugated asbestos paper; 85 per cent magnesia molded with 15 per cent asbestos fiber; laminated asbestos

Physical and Thermal Properties of Some Heat-Insulating Materials

Material	General Composition	Commercial Construction	Density in Lb. per Cu.Ft.	Temp. Limit Deg. F for Commercial Service	Thermal Conductivity B.T.U. per Hr. per Sq.Ft. per In. per °F. = K	Mean Temperature of Sample Deg. F.	Resistance per Inch of Thickness 1/K	Authority
Air	Still air		.08	....	0.157	32	6.37	Int. Critical Tables
Cattle Hair	Hair-felted	Blanket flexible	9.25	100	0.272	60	3.68	.....
Cattle Hair	Hair-felted	Blanket flexible	16.88	....	0.247	86	4.05	Bureau of Standards
Cattle Hair and Jute	Hair and jute felted	Blanket flexible	6.17	100	0.245	60	4.08	.....
Cattle Hair and Other Fiber	Confined with building paper	Blanket flexible	18.72	....	0.2702	86	3.70	Bureau of Standards
Wool Paper and Hair	Laminated	Pipe covering	15.6	100	0.308	50	3.25	.....
Vegetable Corkboard	No artificial binder	Pressed rigid slabs	12.5	....	0.343	86	2.91	Int. Critical Tables
Rock Cork	Rock wool and asphalt binder	Rigid slabs	15.6	100	0.328	86	3.05	Bureau of Standards
Kapok Fiber	Tightly packed	Flexible	.....	100	0.341	78	2.93	Int. Critical Tables
Insulating Boards	Pressed wood pulp	Rigid slabs	17.0	200	0.356	90	2.81	.....
Insulating Boards	Bagasse fiber	Rigid slabs	17.5	200	0.363	90	2.76	.....
Insulating Boards	Licorice roots	Rigid slabs	16.1	200	0.340	81	2.94	J. C. Peebles
Insulating Boards	Pressed wheat straw pulp	Rigid slabs	14.5	200	0.365	90	2.74	.....
Sheetrock	Gypsum and sawdust	Rigid sheet between heavy papers	40.7	....	1.40	90	0.715	A.S.H. & V.E. Guide
Thermax	Shredded wood and cement	Rigid sheet	24.2	200	0.46	72	2.07	J. C. Peebles
Wool Paper Products	Laminated wool felt	Solid pipe covering	24.5	200	0.452	120	2.21	.....
Wool Paper Products	Indented wool felt	Pipe covering	15.0	200	0.337	120	2.97	
Wool Paper Products	Wool paper and asphalt saturated paper—alternated	Pipe covering	31.7	200	0.460	112	2.17	.....
Asbestos Paper Products	Corrugated air-cell type	Pipe covering and sheets	13.7	300	0.632	200	1.58	.....
Asbestos Fiber for Underground Conduit Insulation	Willowed asbestos fiber waterproofed	Filling	8.5	375	0.545	300	1.83	.....
Magnesia	85% magnesia — 15% asbestos	Pipe covering and blocks	14.5	600	0.548	400	1.83	.....
Fire Felt	Long brown asbestos fiber and silicate of soda	Pipe covering and blocks	20.4	700	0.685	500	1.46	.....
Asbestos Paper	With imbedded sponge particles 40 laminations per inch	Pipe covering and blocks	30.0	700	0.590	500	1.71	.....
Asbestos Paper	Indented. 26 laminations per inch	Pipe covering	19.1	700	0.665	500	1.50	.....
Vitrified Asbestos Paper	Asbestos paper — treated with vitrifying solution and baked	Pipe covering and sheets	21.6	700	1.20	300	0.83	.....
Rock Wool	Loose	Filling	10.0	1,000	0.270	90	3.70	Bureau of Standards
Rock Wool	Granulated	Filling	9.42	1,000	0.285	156	3.51	.....
Rock Wool	Felted	Blankets	8.2	1,000	0.408	300	2.45	.....
Rock Wool	Felted with metal jacket	Pipe covering	19.4	1,000	0.532	400	1.88	.....
Rock Wool	Molded with clay and asbestos	Sheets	15.2	1,000	0.384	200	2.60	.....
Spun Glass	Fine glass fibers, perpendicular to heat flow	Blanket	5.56	1,000	0.510	400	1.96	.....
Fire Felt	Short white asbestos fiber and silicate of soda	Pipe covering and sheets	39.6	1,000	1.30	500	0.77	.....
Crumbled Aluminum Foil	Crumbled foil and air—7 layers per 2½ in.	Pipe covering	.....	....	0.680*	500	1.45	.....
Asbestos Fiber Cements	Asbestos fibers only	Cement	66.6	1,000	1.6	200	0.625	.....
Asbestos Millboards	Asbestos pressed	Rigid sheets	60.5	1,000	0.843	86	1.19	Bureau of Standards
Calcium Carbonate	Molded with asbestos	Pipe covering and sheets	23.6	1,000	0.610	400	1.64	.....
Asbestos Fiber Cements	Asbestos and clay	Cement	50.0	1,200	1.2	200	0.83	.....
Rock Wool Cement	Rock wool and clay	Cement	30.0	1,200	1.02	500	0.98	.....
Diatomaceous Earth Bricks	Natural brick cut from earth, heat flow perpendicular to strata	Brick	27.7	1,600	0.92	1,600	1.09	.....
Diatomaceous Earth Blocks	Molded with asbestos, magnesia, and clay	Pipe covering and blocks	26.0	1,600	1.06	1,600	0.94	.....
Monohydrated Bauxite	Molded with asbestos and clay	Pipe covering—blocks and bricks	33.0	1,600	1.20	1,600	0.83	.....
Diatomaceous Earth Cements	Mixed with asbestos, magnesia and clay	Cement	30.0	1,600	0.735	400	1.36	.....
Diatomaceous Earth Fillers	Coarse powder	Filler	20.0	1,600	0.98	1,600	1.02	.....
Diatomaceous Earth Fillers	Fine powder	Filler	17.2	1,600	0.89	1,600	1.12	.....
Portland Cement and Calcined Diatomaceous Earth	Mixture—4 pts. calcined earth to 1 pt. of cement by volume	Poured as concrete	61.8	1,800	2.80	1,600	0.36	.....
Calcined Diatomaceous Earth	Molded and fired	Bricks	38.0	2,000	2.12	1,600	0.47	.....
Calcined Diatomaceous Earth and Clay	Molded and fired	Bricks	42.3	2,500	2.25	1,600	0.44	.....

*Cannot be considered true conductivity, since there is a combination of materials; aluminum foil and air, and a 1-in. thick covering could not be constructed having the same proportionate amount of each material as the seven layers per 2½-in. thick covering.



Variation in Conductivity of Typical Low-Temperature Insulating Materials

No.	Type of Material	Average Density Lb. Cu.Ft.	Average Thermal Conductivity Engineering Units at 20 Deg. Mean	at 100 Deg. Mean
1	Hair felt	10.0	0.227	0.318
2	Rock wool with asphalt binder	14.5	0.267	0.337
3	Rock wool, blown	10.0	0.295	0.335
4	Vegetable cork*	12.5	0.311	0.350
5	Rigid insulating boards	16.1	0.329	0.365
6	Coarse diatomite powder	20.0	0.400	0.435
7	Solid rag felt	24.5	0.398	0.441
8	Coarsely shredded wood with magnesite cement	25.8	0.528	0.632

*International Critical Tables, vol. 2, p. 315.

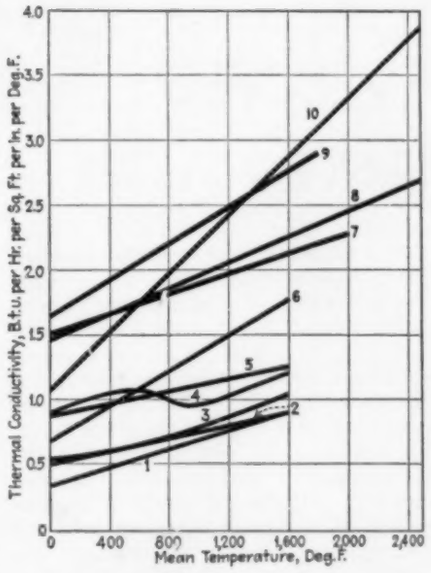
papers of various kinds, some containing indentations to provide air spaces, some containing small particles of sponge to space the laminations; various types of materials consisting only of asbestos fiber molded to shape with inorganic binders; and various molded types of rock-wool products.

For the higher temperatures—from 1,200 deg. F. to 2,500 deg. F.—the available insulations are much more limited. For the lower part of this temperature span, diatomaceous earth may be used in either its natural state, in the form of bricks, or, where larger sizes are desirable, it may be bonded with a small quantity of asbestos fiber and magnesium carbonate. For the upper part of the temperature span, the diatomaceous earth is bonded with such materials as clays and grog, and calcined at temperatures higher than those for which the material is recommended for service.

There also is available a general line of cements, each specially designed for a specific purpose. The asbestos cements are generally not used as insulating materials in themselves, but find application mainly as finishing cements to protect other insulations applied directly to the unit. However, there are magnesia cements, diatomaceous earth cements, and rock-wool cements which are good insulations and are used to insulate irregular surfaces where pipe covering or blocks cannot be readily fitted.

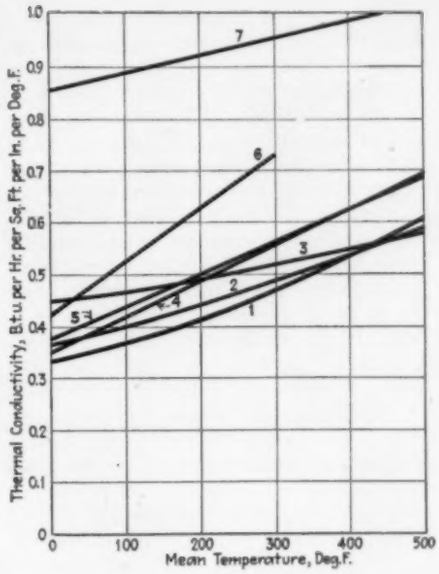
While all these developments were in progress, improvements in methods and technique of testing also were being made. Today there are available for the engineer insulations designed for all conditions of service, from the lowest temperatures in the refrigeration field to the highest industrial temperatures. These, together with accurate technical information on their various thermal and mechanical properties, make it comparatively simple for the industrial engineer to decide upon the type of insulation necessary for his particular problem.

Accurate testing of insulating materials is of great importance in connection with their development and proper use. The National Research Council has appointed a committee to study the various methods in use for determining thermal properties, and this committee has definitely stated just what types of testing apparatus are capable of giving



Variation in Conductivity of Typical High-Temperature Insulating Materials

No.	Type of Material	Average Density Lb. Cu.Ft.	Average Thermal Conductivity Engineering Units at 400 Deg. Mean	at 1600 Deg. Mean
1	Diatomic powder	17.2	0.48	0.89
2	Solid diatomite heat flow perpendicular to strata	27.7	0.61	0.92
3	Molded diatomite with binder	26.0	0.61	1.06
4	Monohydrated bauxite with binder	33.0	1.04	1.20
5	Solid diatomite heat flow parallel to strata	27.7	0.97	1.27
6	Clay with cork granules, fired	29.8	0.92	1.77
7	Diatomite brick fired	38.0	1.65	2.12
8	Diatomite brick with binder, fired	42.3	1.65	2.25
9	Diatomite with Portland cement, fired	61.8	1.94	2.80
10	Clay with cork granules, fired	36.0	1.53	2.87



Variation in Conductivity of Typical Medium-Temperature Insulating Materials

No.	Type of Material	Average Thermal Conductivity Engineering Units at 100 Deg. Mean	at 500 Deg. Mean
1	Rock wool pipe covering	0.36	0.61
2	Laminated asbestos pipe and sponge particles	0.40	0.59
3	85% magnesia	0.47	0.58
4	Crumpled aluminum foil	0.42	0.68
5	Molded asbestos fiber and sodium silicate	0.44	0.69
6	Air-cell type pipe covering	0.52	At 300 deg. mean 0.73
7	Insulating cement	0.87	1.02

results with sufficient accuracy to be acceptable.

In passing, it might be mentioned that only recently has an apparatus been available for directly measuring conductivities above 1,500 deg. F. mean temperature with sufficient accuracy, and consequently the general rule has been to extrapolate the conductivity curves through the higher mean temperatures. It is hoped before long to have direct determinations on materials in this field.

In general an insulation must possess the highest thermal efficiency consistent with the mechanical strength necessary to render the service desired. It must be chemically and physically stable; that is, it must not rot, mold, powder, oxidize, disintegrate, crack, crumble, shrink, or deteriorate in any way that will impair its original thermal and mechanical efficiency.

From the economical standpoint insulation must be easily applied; it must have sufficient insulating properties so that the last ½ in. increment will effect a saving sufficient to pay the fixed charges on the cost of this increment; and lastly, it must be durable under the conditions of service.

There is no insulation suitable for all conditions of service, and there are places where conditions are such that

no insulation will function with maximum efficiency. In these cases selection must be made to meet the major requirements at the expense of the minor desirable qualities. It is also for these cases that continuous attempts are made to produce insulations which will more nearly meet all the requirements.

In order for an insulation to be permanently effective at low temperatures, it must be highly resistant to moisture penetration or entirely protected from the entry of moisture. Further, it must not promote or be susceptible to mold growth. To date, no insulation has been found that is entirely impervious to or unaffected by moisture, and the cost of protecting completely an insulation against moisture is in most cases prohibitive. It must be repellent to vermin, or at least it should not harbor them, particularly when the insulation is used in connection with food storage. All the commercial low-temperature insulations now on the market have sufficient structural strength in their manufactured state; but for satisfactory service they must maintain that strength, even with the continued action of moisture on the surface. Asphalt coatings come closer to solving perfectly this problem than any other method so far found. Illustrative of the importance of preventing moisture ingress is the statement from A.S.R.E. circular No. 1, p. 90, that each 1 per cent gain in weight due to moisture absorption causes the heat conductivity to increase by about 5 per cent.

In the low-pressure field, insulations are mainly required to be sturdy, light in weight to permit of as light structural supports as possible, easy to apply, and sufficiently effective to show an adequate return on the investment.

For the medium- and high-temperature fields, insulations of a more refractory nature are required; insulations which will not shrink, crack, spall, or unduly compress under reasonable loads. The material must be proof against chemical decomposition or dehydration which would impair its insulating value.

In the choice of insulating material for a specific purpose the guiding factors are temperature, thickness and weight permissible, mechanical strength and resistance, restrictions on method of application, presence of fumes or moisture, and the over-all cost to obtain desired heat saving and low maintenance charges. The cheapest material often does not represent the most economical choice when over-all costs and technical satisfaction are properly considered. While the general information and data here given may be helpful as broad guides, the best procedure is to consult manufacturers of the materials in question for specific recommendations. It is highly probable that the solution to an analogous problem already exists, and performance records can be produced which will definitely show results to be expected. In judging data on physical properties it might be well to satisfy one's self that they are the result of approved methods and represent standard production material whose physical properties are maintained with satisfactorily small variation by adequate control.

The authors acknowledge the assistance of C. E. Weinland in preparation of charts and checking of data here given against previously published results.

▼ ▼ ▼

NEW METHOD DEVELOPED FOR CEMENT BURNING

A NEW solution of the problem of increased economy of operating a rotary kiln for burning cement is an invention of Dr. O. Lellep which is described in detail in *Rock Products*, vol. 25, No. 5, p. 42, and in his dissertation, Technical Hochschule Braunschweig, Germany, 1930. The fundamental idea of this invention is the installation of a traveling grate which is placed in a chamber beyond the rotary kiln. The hot waste gases of the kiln pass through this chamber above the grate which conveys the raw meal in the opposite direction from the feed opening toward the rotary kiln. In order to obtain intimate contact between the hot gases and the cold raw meal particles, the gases are sucked through the layer of the raw meal and the traveling grate.

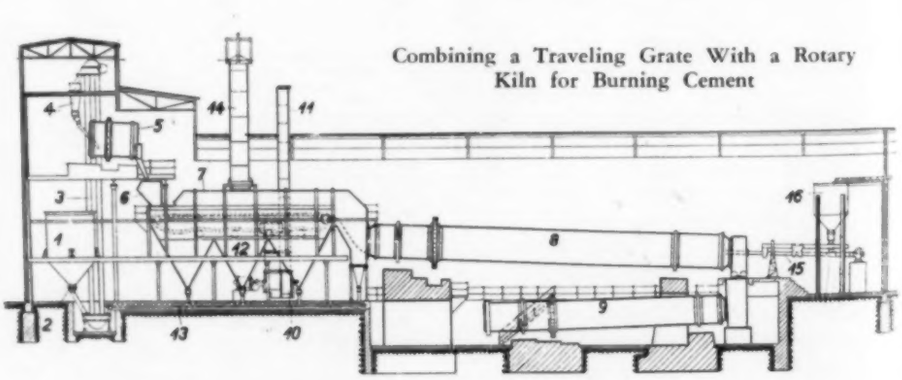
To insure complete success in this exchange of heat, it is necessary to introduce the raw material in a convenient shape. The invention covers the forming of the raw meal into small balls by the addition of a small quantity of water. As the gases are thoroughly split up by the great number of small balls, an ideal transfer of heat from the gases to the nodules is obtained.

This idea of utilizing the sensible heat in the rotary kiln gases on the traveling grate by nodulizing the raw meal shows striking advantages for the economical operation of such a plant. The waste heat losses are reduced to a minimum. Furthermore, the dust content of the waste gases is reduced to practically nothing. Another advantage is the possibility of shortening the length of the rotary kiln. The kiln required for the new plant, in order to finish the burning, will have a length of only 80 to 120 ft.

Following is a brief description of the plant: The raw meal is handled from a silo (1) by a screw (2) and an elevator (3) into a small feeding bin (4). From this bin the raw meal is uniformly fed to a drum (5), where it is subjected to a fine spray of water and, by means of rotation, the nodules are formed; these are collected in a hopper (6), which feeds the traveling grate (7). The material passes over the slowly moving grates to the kiln (8) and from the kiln, in the usual manner to the cooler (9).

The hot gases pass in countercurrent through the kiln and by means of a fan (10) are sucked through the layer of nodules and the grate (7), to be finally discharged through the stack (11).

The particles falling through the grate are collected in air- and dust-tight hoppers (12) and returned to the elevator (3) by means of a screw conveyor (13). On top of the grate inclosure is placed an auxiliary chimney (14) which can be closed by a flap damper. This chimney is used only when starting the plant. During normal manufacture it is closed, so that the hot gases are compelled to pass through the grate.



Combining a Traveling Grate With a Rotary Kiln for Burning Cement

WHEN ELECTRICAL HEATING PAYS

By JAMES A. LEE
Managing Editor, Chem. & Met.

Convenience, cleanliness, ease of control and working conditions are important factors in operating cost and often influence the choice of equipment and fuel regardless of comparative costs on B.t.u. basis

IN THE process industries, electricity has certain advantages for many heating purposes that are not offered by any fuel. It would be a most extraordinary development that would permit gas, oil or coal to duplicate the results produced daily by arc furnaces manufacturing calcium carbide and abrasives; electrically heated lehrs annealing glass; and strip heaters attached to pipe lines used for maintaining the temperature of the contents. The results made possible with such appliances and the difficulty of producing equally favorable results with any form of fuel equipment illustrate the economic folly of those who seek to rest their case on the alleged technology of comparative fuel values, instead of upon the economics of the heating operation as a whole.

Advantages of electric heating of unquestioned, though indefinite, economic value should be recognized by the chemical engineer. Among these advantages must be included absence of heat and odor from spent gases; elimination of products of combustion; control of atmosphere; decreased dependence upon the human element; possibility of maintaining local heating zones without materially affecting any other section of the furnace; locating the furnace in line of production or in a position to which it may be inconvenient, or inadvisable, to run pipe lines; automatic starting or stopping from a time clock; and automatic operation at night without an attendant. Among the other advantages are maintenance of a given atmosphere of gas such as hydrogen, without muffles; relative high heat balance of the furnace; influence upon the electric load and rate for the plant as a whole, particularly by operation at night; and in general, all those indirect advantages of electric equipment that may influence the quality or over-all cost of the ultimate product, or working conditions for the men. These factors must be investigated by the design engineer after due consideration has been given to the heat cost of the source of heat available.

Advantages in Plant Management

The location of the equipment in the plant, the nature of the production operations in its vicinity, and the labor difficulties which may have been experienced due to poor working conditions, largely determine the standard of cleanliness and working conditions. These standards are particularly important in some departments when plants are laid out on a straight-line basis of production, rather than with all heating operations concentrated in one building. Unquestionably oil is cleaner than coal, gas cleaner than oil, and electricity cleaner than either. Whether improved working conditions can be capitalized in reduced over-all costs can be determined only by investigation of the local situation by the plant engineers, not only with view to the effect on the individual furnace operation but also with consideration given to the possibility of increased production, which generally results when work is made easier and more pleasant.

In some forms of equipment, one source of heat may appear to result in lower maintenance than other sources. In the case of electricity there is a choice of resistors, the ultimate selection of which must be dictated by the application and the judgment of the equipment builder.

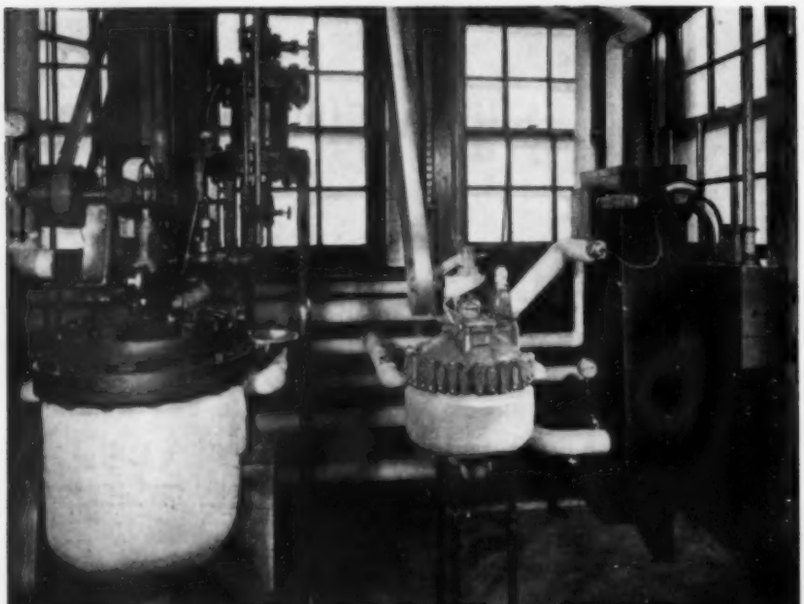
In some cases the nature of the atmosphere in the furnace is important. Atmosphere suitable for one product may not produce the best results in another. Products of combustion of the fuel-fired equipment consist of nitrogen, carbon monoxide, carbon dioxide, water vapor, sulphur dioxide or higher oxides, and at times free air and uncombined carbon. Sometimes these products may be prevented from coming into contact with the objects being heated by inserting a muffle in the furnace. In electric equipment of the metallic resistor type, the chamber normally contains comparatively inactive air, and will be oxidizing until the oxygen in the air has been consumed in burning combustible matter present, by combination with the surface of the work to form oxide. If the equipment is airtight or has no great infiltration of air, oxidation stops, and the heating proceeds in an atmosphere which tends to be neutral.

Electrical heating equipment of suitable design can be operated automatically, producing under shop conditions identical results day after day, uniformly and continuously and with common labor in place of so-called expert operators that were formerly required. Automatic operation permits production of a superior product without spoilage or rejection of material. The fuel costs may be only 1 per cent of the factory cost, whereas the value of the rejected parts, labor of handling such parts, additional equipment made necessary in order to get out a definite production, additional testing and inspection, may increase the factory cost 15 per cent.

B.T.U. Costs Not Vital Factor

Assuming that electrical energy would cost twice as much as that of other fuels and that rejects are reduced to zero with electric heat, then the factory cost would be reduced 13 per cent (K. E. Rogers, lecture to Ind. Elec. Heating School of the N.E.L.A., June 10, 1931). It is obvious, therefore, that one could not afford to use fuel for heating purposes in many applications on quality production in industrial plants if the fuel were obtained for nothing.

The application of electric heating to industry, as R. M. Keeney, of the Connecticut Light & Power Co., has so well stated, has passed through three broad stages of development: electric smelting, electric melting, and industrial electric heating. We are now in the third of these stages, which, as at present construed, due to temperature limitations of existing furnaces, is mainly resistance-heating up to a temperature of about 1,850 deg. F. Progress in the application has proceeded in a logical manner in conformance with the requirements of the industrial progress of the world.



Electrical-Hot Oil Circulating System Heated by Container Resistance, With Automatic Temperature Control Within 3 Deg., Used in Making Pharmaceuticals

Its development has been from extremely high-temperature processes which can be conducted only in an arc or induction furnace down through the whole range of processes to simple drying and baking at low temperatures.

The possible applications of the container-resistance principle of heating are many and varied and apparently limited only by the ingenuity of the designer. Some of the types of equipment which have been adapted to this use at present are rolls for paper and textile machinery, kettles, vapor-phase oil-cracking stills, high temperature and pressure heaters for oil, steam or vapor generators, evaporators, instantaneous heaters for liquids, and varnish compounding systems (R. A. Carleton, *Chem. & Met.*, Vol. 35, p. 102).

In some classes of apparatus the container is best made the resisting element. In others the resistor may consist of plates or tubes inside the container or shell. These are made part of a low-voltage electric circuit. In some instances the container may form a part of the circuit but may not be required as a portion of the heating element. In any case, the heating element is of comparatively high resistance, and where this does not include the shell, the latter is constructed of material having the lowest practicably obtained resistance consistent with the other physical or chemically resistant properties required.

The container-resistance method has the particular advantage that it readily lends itself to convenient constructions, such as pipe stills or tubular heaters, where the tube itself constitutes the heating element and is heated by the passage of the electric current through its walls, the liquid being circulated by pump at a relatively high velocity through the tubes.

In such constructions, high rates of heat input, in some instances 80,000 B.t.u. per square foot of heating surface per hour, may be utilized, resulting in an extremely compact and inexpensive heating mechanism, where, due to the small quantity of metal required, special or relatively costly metals highly resistant to chemical corrosion are applicable. As a high liquid velocity is employed, the tubes may be of small diameter and the equipment may thus be constructed for operation under extremely high pressures at high temperatures. For instance, for continuous operation at temperatures up to 1,600 deg. F. at pressures up to 3,000 lb. per square inch or more.

Electric heat utilization for process operations by means of hot oil circulation provides simplicity, as the circulating type of electric heater may be installed near the jacketed kettle or tank and the hot oil circulated through the compact closed circulating system by means of a hot oil circulating pump.

Space and Strip Heaters

Many space heaters are used in low-temperature baking and drying ovens; in the heating of tanks containing water, pitch, oil or chemicals; and for preventing the freezing of water lines and valves. Oven heaters are used to dry chemicals and to heat oil. At least one chemical company heats air to assist in a certain chemical reaction and another large corporation has found the electric oven the most satisfactory means of drying samples, due to the ease of temperature control.

Medium temperature heaters are used chiefly in heating liquids in melting pots. And there are several large installations of electrically heated oil-circulating systems where fats or oils which congeal must pass through pipes from one operation to another.

Strip heaters clamped to pipes are used in a byproduct coke plant for heating and maintaining the temperature of the tar that is pumped around the plant. This type is used also on pipe lines carrying molten asphalt and lead.

For this type of work it is necessary only to provide sufficient heat to maintain temperature—in other words, to offset radiation losses. The heaters are attached along the bottom of a pipe and the whole job is covered with insulation. The usual procedure is to put a tight-covering insulating material over the job, using one or two sizes larger than the pipe being covered. In this way it permits an air space at the bottom, which is desirable when insulating electric heat. Many of these installations are thermostatically controlled so as to maintain a definite temperature. Some of them are wired by using half voltage for normal operation and so wired that several voltages can be used if for any reason the line is shut down and the material solidified.

Uses in Chemicals Manufacture

The production of chemically pure hydrochloric acid, which was described by C. M. Hoff, of the Grasselli Chemical Co. (Trans. Am. Elec. Chem. Soc., 1928), is an excellent example of how electric heating can be applied in the chemical industry, in some cases to very old processes, with many advantages. Results included a continuous process that utilized electrical energy in place of fuel, reduced greatly the operating costs, advanced the quality of the product, and improved working conditions.

A vegetable oil plant in California is using electric steam superheaters to supply suitable steam for its processes. Electricity was chosen in preference to a combustion method because of the improved fire and insurance risk resulting. It is necessary to superheat the steam at a point near the center of the factories, and live steam is not available.

In the manufacture of calcium cyanamide, electric heat is immensely important. The Niagara Falls plant of the American Cyanamid Co. contains eight carbide-making furnaces: four 4,000-hp. furnaces with a capacity of 22 tons of calcium carbide per day, two 16,000-hp. furnaces with a capacity of 98 tons per day each, two 30,000-hp. furnaces each with a capacity of 185 tons. The oblong assembly of five 20x22x100-in. carbon electrodes, suspended in the largest furnaces, weighs complete with holder about 10 tons. The charge, a mixture of lime and coke, is fed around the electrodes. The tremendous current of electricity passing between the electrodes melts the lime, which combines with the coke, forming calcium carbide and carbon monoxide.

Electric heat has solved an important space problem in the plant of a rubber specialties manufacturer. Platen presses

with electric elements have increased production through enormous improvements in working conditions. Working conditions now are not oppressive; close temperature regulation is easily obtained; extreme flexibility of operation is possible; and presses may be shut down or put into operation almost instantaneously. Imperfectly vulcanized goods, due to poorly heated platens, have been practically eliminated and the whole operation of the plant has been increased by the change from steam to electric heating.

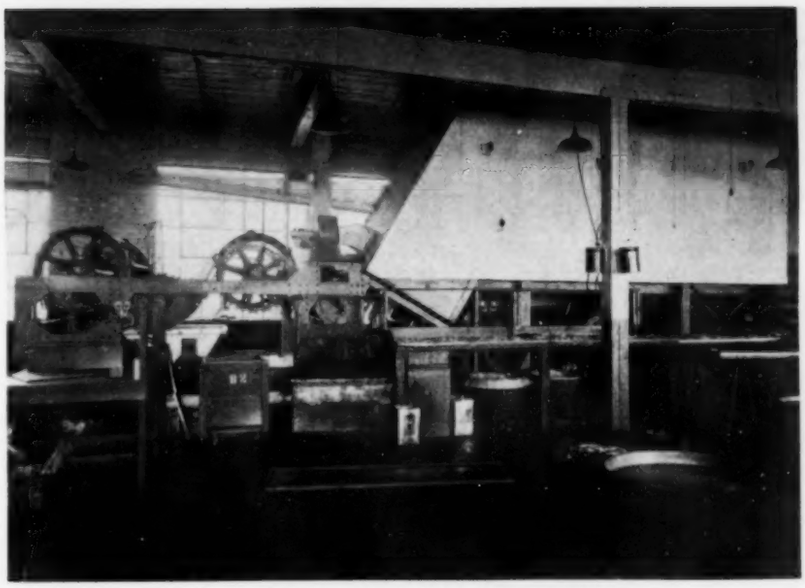
The principal methods through which electric heating is used in the paper industry are the electric steam boiler and the electric paper dryer. Electric boilers have been operated in paper mills for about eight years. The use of electrically generated steam in the paper industry is purely one of economics, as it in no way affects the process. The electric steam generator has found wide application in this industry for utilizing surplus power.

The Alexander electric paper dryer was first used on July 7, 1924. It operates on a different principle from the steam dryer in that a large volume of air is not used for the removal of the moisture but moisture is removed as superheated steam. The power consumption of the dryer installed in a plant at Port Edwards, Wis., is about 0.84 kw.-hr. per pound of paper dried, or approximately 90 per cent efficiency. There is obtained 2.07 lb. of steam per pound of paper dried as a byproduct, or approximately 2,198 B.t.u. byproduct heat per pound of paper dried, which energy is available for other work.

There are a large number of advantages in using the electric dryer besides the economy of the drying of the paper itself, these including saving in the size of the dryer unit, which means lower initial cost in the machine room, and also the maintenance; reduction in lubrication cost; elimination of paper breakage; improved working conditions; elimination of steam, which means the elimination of everything that goes with it; and uniformity of drying.

Glass Industry a Large User

In the glass industry, the two principal applications for electric heating are for glass troughs and lehrs. Formerly, large bottles and carboys were made by hand and then placed in brick annealing kilns which were fired to a fairly high temperature and allowed to cool gradually over a period of a week or more. Such a method could not take care of the output of an automatic machine turning out 7,000 or 8,000 large bottles per day. Close control was impossible in the old kilns and the inadequate annealing did not always give the even strength required in the product. Machine production, therefore, demanded continuous annealing, and to do this efficiently meant doing it in the shortest possible time. In the Alton plant of the Illinois Glass Co. the practical solution of the problem was found in the application of electric heating in tunnel lehrs through which the product is carried on a continuous belt.



Lacquer Drying Oven Heated by Electricity

Although the unit cost of the electric heating was much higher than for oil or gas, the more efficient utilization of heat in the improved design kiln and precision of control actually made the process more economical. Even greater savings resulted from consistently good annealing in such greatly reduced time.

In this country there are over 100 electrically heated lehrs in operation, annealing various kinds and sizes of ware. In the plant of the West Coast Glass Co., according to R. M. Cherry (*Chem. & Met.*, Vol. 38, p. 400, 1931), they are used for the annealing of various types and sizes of bottles and jars, and the entire output of this plant is annealed electrically. The use of electrically heated lehrs has extended to the plate-glass industry, where about 12 have been installed to date. The hourly output of the lehr is about 12 tons of glass. The power consumption varies with the production and thickness of glass being annealed, usually between 250 and 300 kw.-hr. per hour. For a production of 12 tons per hour, this means about 25 kw.-hr., or 25c. (at 1c. per kilowatt-hour), per ton of glass annealed. At an annealing cost of 25c. per ton of glass entering the lehr, this means a cost of approximately $0.00064 per square foot of ¼-in. finished glass, or about 16 sq.ft. of glass annealed for 1c.

The temperature characteristics can be readily changed for different kinds and sizes of ware by adjustment of the instrument setting. This, together with a variable speed adjustment on the conveyor drive, gives complete control of the annealing cycle. The precise control of the temperature time curve permits a shorter annealing time, which in turn permits the use of shorter lehrs for a given width and saves considerably in floor space.

Ceramics and Refractories

In the production of many types of earthenware, tile, brick, refractories, heat is a necessity and the use of electric heat already a fact in some plants and a worth-while possibility in others. Electric furnaces are used to heat charges of chinaware from room temperature to 1,600 deg. F., which then cool to 200 deg. F., all in a 9-hour day.

A continuous type kiln equipped with electric heating elements was installed in one of the largest tile plants in the country. The furnace was designed for burning decorating tile. In the old type kiln it was extremely difficult to match colors from the same batch of the tile burned in different kilns, and in fact tile from the same kiln would vary in color. With electric heat this is no longer the case—on the contrary, colors can now be matched exactly and reproduced at will. As this kiln is in the line of production, the tile is laid directly on the kiln conveyor from the press. The tile is inspected and packed as it emerges from the kiln.

Manufactured abrasives depend entirely upon the arc furnace or the high-temperature resistance furnace for their production. Without electric heat there would be no abrasive industry as it now exists. After the successful operation of the electric oven for baking japan, it was introduced into the abrasive industry for the drying and preliminary baking of grinding wheels after they are formed. These wheels are thoroughly dried out before being finally baked at a high temperature. Electric heating has proved successful for such operation where local conditions justify its use. Several abrasive plants now have an installed capacity of electric ovens exceeding 500 kw.

STRUCTURAL MATERIALS FOR MODERN HEAT TECHNOLOGY

By F. H. NORTON
Department of Ceramics
Massachusetts Institute of Technology
Cambridge, Mass.

ALTHOUGH refractories are used for a great many purposes under conditions of high temperature, their function can be made more clear if we classify them into five main groups according to the purpose which they serve. A refractory satisfactory for one purpose may be quite unsuited for another, and, as the cost of maintaining a furnace depends largely on the proper selection of the refractory, their properties require careful consideration.

The first group consists of those used to confine heat within a definite space. An open fire for heating is not very efficient because most of the heat is wasted, but by surrounding the fire with a refractory container, much more of the heat is used. The thicker the walls, the less heat is lost through them, but on the other hand the more heat is absorbed in the brickwork. When deciding on the correct thickness we must take into account whether the furnace is maintained at a uniform temperature or whether the temperature is periodically raised. In the former case a massive wall is not such a disadvantage, but in the latter, it absorbs considerable heat. This group includes furnace walls and roofs. Refractories for this condition should, of course, have a fusion point higher than the maximum temperature of use, and if the temperature changes rapidly should be able to resist spalling.

The second group comprises refractories for containing a charge, such as the blocks in the bottom and sides of a glass tank or the walls of a coke oven. In this case it is necessary to have a refractory that will not only withstand the temperature but also one that is not rapidly eaten away by the charge. This group does not often have to withstand extremely high temperatures, but many types of molten charge are very active.

In the third group are refractories used to protect structural members from the influence of a high temperature. In many cases the structure serves only to hold the refractories in place, but some parts, like door frames and burner boxes, need protection from the intense heat.

The next group consists of those parts of the furnace that conduct heat from the combustion gases to the charge through a tight wall. It is exemplified by muffles, recuperators, and retorts. The prime necessity for the refractory is a good thermal conductivity, and in most cases an impermeable structure. A high mechanical strength also is desirable, because it allows thinner walls and thereby a greater heat flow.

The last group comprises refractories for absorbing heat, such as regenerator checkers. Brick for this use should have a high density and great thermal conductivity, and in some cases should have resistance to slag.

Judging Their Properties

In one type of service some properties are more important than in others, but, needless to say, there is no one refractory having all the desirable properties; so that to obtain some we must sacrifice others. Information on materials for very high temperatures was given in *Chem. & Met.*, February, 1932, p. 85.

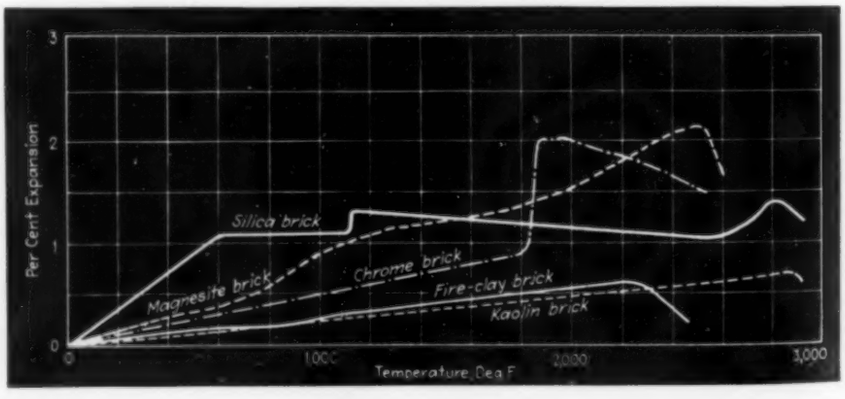
In the first place the refractory obviously must have a fusion point above the maximum furnace temperature. It need not, however, be very much above if its other qualities are satisfactory. For example, a very satisfactory brick may fuse only 100 deg. above the furnace temperature, while an unsatisfactory one may run 600 deg. above. Therefore, the value of a brick cannot be judged solely by its fusion point.

The thermal conductivity of a refractory is an important property in most cases. For furnace walls the conductivity should be as low as possible, in order to prevent heat loss. On the other hand, such parts as muffles and recuperator tiles require the highest possible thermal conductivity for efficient operation. The thermal conductivity of refractories varies over a wide range, so that it is often possible to select materials having the desired properties.

Refractories are seldom fired at temperatures as high as those occurring in use. Many bricks will therefore show some expansion or contraction in service. For high temperature use this volume change is quite serious, so for this service only well-burned bricks can be used. The coefficient of expansion of a refractory is important, as it affects the expansion of a structure on heating as well as influencing the tendency to spall.

The ability of a refractory to resist temperature changes in service is of the utmost importance in most types of intermittent furnaces. This resistance to temperature change depends mainly on its coefficient of expansion in the spalling range—that is, at about red heat—and the flexibility of its structure. Silica, magnesite, and chrome refractories are quite sensitive to temperature changes, due to their high coefficient

Fig. 1—Expansion of Refractories With Temperature



of expansion, while fireclay and mullite refractories are quite resistant.

Many refractories are required to carry a heavy load at high temperatures, as piers under a hearth or muffle. Refractories for this condition should be hard burned and have a minimum of fluxing elements. Silica and mullite brick show up among the best under conditions of load.

Probably the most severe action tending to shorten the life of a refractory is that due to slag. There are many types of slag, and for each one there is a refractory best able to resist its action. The higher the furnace temperature, the more active is the slag in attacking the refractories. In many cases no refractory can be found to stand up long, so water cooling must be resorted to.

Types of Refractories

There are a number of types of refractory available in commercial quantities. The most commonly used are bricks of fireclay, because they are relatively inexpensive and resist temperature changes well. However, they are not resistant to many types of slag. Fireclay brick are used in all cases where the conditions are not too severe. Perhaps 75 per cent of all refractories manufactured in the United States are of fireclay.

Silica refractories are used in furnaces that are maintained at a fairly constant temperature, especially where they must carry a load at high temperatures. They cost about the same as high-grade fireclay bricks and are resistant to acid slags. They are used in the roofs of open-hearth furnaces and in continuous glass tanks.

A number of bricks of the fireclay type but made of purer or of higher alumina materials are on the market, such as kaolin and diaspore bricks. These are naturally more expensive than fireclay bricks, but have an advantage under severe conditions, such as oil-fired boiler furnaces, rotary cement kilns, and piers under hearths.

Magnesite bricks are used mainly to resist the action of basic slag. They are relatively expensive and are rather sensitive to temperature changes, which limits their use mainly to hearths in the steel industry.

Chrome bricks, made from chromite ore, are a neutral refractory and quite resistant to many types of slag. Like magnesite bricks they are relatively expensive and sensitive to temperature changes. They are used to separate magnesite and silica brick in the open-hearth furnace, and in hearths where slag conditions are severe.

Recently a new type of refractory has come into use, which promises to change many of our ideas of furnace design. This is the insulating type of refractory having good resistance to high temperatures and at the same time a low thermal conductivity and a low weight. While it is not resistant to slag there are many furnaces where it shows very interesting results.

In the accompanying table are assembled the more important properties of the common types of refractories, and in Figs. 1 and 2 are given the values of thermal conductivity and expansion.

Selecting the Refractory

In order to select the best refractory for a given purpose, there are a number of important considerations. In the first place, if the temperature changes are rapid, as in an oil-fired boiler furnace, we are limited to those refractories which are able to withstand these conditions. This would include fireclay, high alumina, and silicon carbide refractories. Next the slag action must be considered. Some types of fireclay or aluminous bricks will withstand a certain slag better than others, but generally this cannot be determined without actual tests.

When the furnace temperatures are substantially uniform, silica, magnesite, and chrome brick become available. Silica is particularly valuable in the roofs of high-temperature furnaces such as the open-hearth or the glass tank. Its high resistance to load makes it stable almost up to its fusion point. Magnesite and chrome are resistant to many metallurgical slags and are used in hearths and side walls.

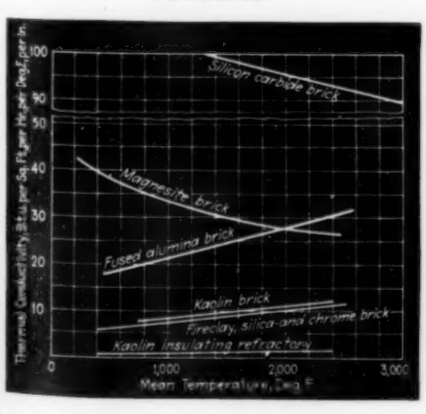
After this type of refractory has been selected the consumer often has to consider which of several competitive brands will serve most economically. While nothing will take the place of a service test, laboratory data, if intelligently interpreted, will be of great assistance. The cost of the refractories is not measured by the price per thousand bricks but by their cost per unit of product. The lowest priced brick is seldom the most economical. Often a more expensive brand will, in the end, be the most economical, because of longer life and more freedom from shutdowns. Again, in choosing a brand, the experience and dependability of the manufacturer should be considered.

The majority of refractories are used as straight brick 9x4½x2½ in. However, there are many standard shapes, such as arch brick, soaps, splits and tiles, which can be profitably used in any furnace construction. These standard shapes are stocked by all manufacturers, and can therefore be used freely in any

PROPERTIES OF REFRACTORIES

Type of Brick	No. 1 Fireclay	Kaolin	Kaolin Refractory Insulator	Silica	Magnesite	Chrome	Silicon Carbide
Typical Composition in Per Cent	42 Al_2O_3 54 SiO_2 2 Flux	45 Al_2O_3 52 SiO_2 1 Flux	45 Al_2O_3 52 SiO_2 1 Flux	96 SiO_2	85 MgO 7 Fe_2O_3 3 CaO	44 Cr_2O_3 16 FeO 15 MgO 15 Al_2O_3 5 SiO_2	100 SiC
Fusion Point, deg. F.	3050	3200	3200	3050	4000	4000	4000 (decom)
Load resistance, Temp. deg. F. for 10 per cent shrink. at 25 lb. per sq.in.	2700	2900	....	3000	2500	2600	3100
Resistance to spalling in cycles	20	20	...	None	1	2	25
Wt. / brick (std. 9-in.)	7.5	7.5	1.8	6.5	10	10.5	9
Porosity in per cent	20–30	20	80	25	...	...	...
Spec. heat (60-1200 deg. F.)	0.23	0.23	0.23	0.23	0.27	0.20	0.20
Relative slag resistance							
Acid steel slag	Fair	Fair	Poor	Good	Fair	Good	Good
Basic steel slag	Poor	Poor	Poor	Poor	Good	Good	Good
Mill scale	Poor	Poor	Poor	Poor	Good	Good	Fair
Coal ash slag	Fair	Fair	Poor	Fair	Good	Fair	Good
Approx. cost per thousand 9-in. equivalent in dollars	35–40	260	170	40–50	450	270	1000

Fig. 2—Thermal Conductivity of Refractories



design. There are also numerous special shapes that are stocked by some manufacturers, such as coke-oven shapes, locomotive tile, glass-tank blocks, etc. The manufacturers' catalogs should be consulted when using any of these shapes in a new design.

Refractory Bonding Agents

There are three types of refractory cement in general use. High-temperature cement is refractory enough not to vitrify strongly at the furnace temperature, but serves only to make a tight wall. On the other hand, vitrifying cements become hard at the furnace temperature and form a strong wall, even at comparatively low temperatures. Air-setting cements contain sodium silicate and harden on drying.

The cements must be properly used in laying up bricks to obtain good results. Thick joints should not be used, as the cement is always weaker than the brick. Nor should the trowel be used: instead, the cement, thinned to a slip, should be poured over the top of the wall with a dipper and the next course tapped into place. In some cases brickwork is laid up dry with a great saving in labor.

A cement should have good working properties, little shrinkage, a good adhesion to the brick surface, and the proper vitrifying point. Cements usually contain a considerable proportion of fine grog to reduce the shrinkage. Low vitrifying cements, in addition, have a flux or low-temperature clay added.

Care should be taken, when heating up a new furnace, to dry out the moisture in the brickwork slowly. Otherwise, much damage may be done as the steam is forced out of the pores.

Coatings are used to cover the inner surface of a furnace wall to make it tight or protect it from slag or abrasion. While many extravagant claims have been made for particular brands, coatings may have at times a real protective value.

Coatings are applied with a sponge, brush, or cement gun. The correct coating is a thin layer that penetrates into all the cracks and pores, not only to seal them but to increase the adherence. In case a thicker coating is desired, the material must be put on in several layers.

A plastic is a mixture of clay and grog of about the same nature as that from which a brick is molded. This material is used to make up complicated shapes in the furnace by ramming against a wooden mold or to patch eroded brickwork. A good plastic should have little shrinkage, should adhere to the wall, and should burn to sufficient strength at the operating temperature.

Plastics are generally applied by cleaning the brickwork and ramming in the patches with a mallet until a firm and homogeneous structure is attained.

REFRIGERATION SYSTEMS AR

DEMANDS OF M

By L. H. MORRISON and H. C. DUUS

Associate Editor, Power
New York City

Ammonia Department
E. I. du Pont de Nemours & Co.
Wilmington, Del.

REFRIGERATION is no longer the exclusive tool of the ice maker; it has become a necessity in hundreds of chemical processes. In some instances the old-time ice-making equipment has been adopted without change, while in others special methods have been introduced and almost daily new applications are being made.

A comparatively new art, refrigeration received its first real impetus with the development of the ammonia compression machine by Linde in 1873. Its most important applications are in the preservation of foods. Previous to the adoption of the Eighteenth Amendment the brewing industry was a very important application, and a number of related biochemical industries, such as baking, candy making, and ice cream manufacture, still demand large tonnages. In the last few years the necessities of regulating the temperature and humidity of air in chemical industries has given a decided impetus to air-conditioning, a field closely related to refrigeration. More recently the strictly chemical industries have extensively adopted refrigeration processes, and most chemical plants employ artificial cooling for the control of delicate chemical operations.

Aside from the control of reactions, refrigeration is most commonly used for the separation of materials which in general become less and less compatible as the temperature is lowered. Recovery of sodium nitrate from caliche, wax separation in oil refining, recovery of condensible vapors (casinghead gasoline in natural gas, SO_2 in sulphuric acid manufacture, ammonia in the Haber process), "salting out" in soap manufacture—are examples of diverse processes which are based on this general principle. Most of the details of actual processes are kept more or less secret, but it is fairly evident that the art of refrigeration is an important tool for the chemical engineer.

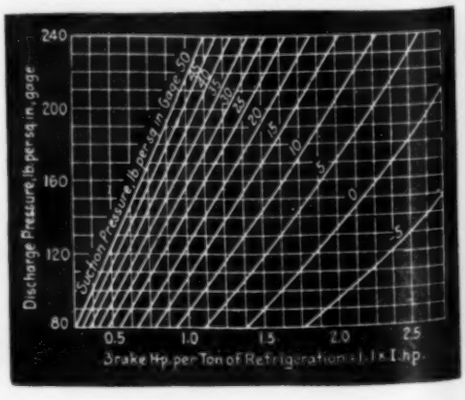
A refrigerant in its broadest sense may be defined as any material which is used for abstracting heat. In a narrower but more commonly used sense, the term refers only to those materials which are used in mechanical refrigeration.

Four Circulating Methods

Mechanical refrigeration includes those processes in which the refrigerant is recovered and recirculated, as distinguished from those in which the spent refrigerant is wasted (ice refrigeration, ice cream freezing by salt-ice mixtures, cold ground waters in spring houses). Mechanical refrigeration falls into four general groupings, depending on the method used in recirculating the refrigerant: *compression, absorption, adsorption, and evaporation.*

Compression systems resort to either a positive displacement mechanism (reciprocating or rotary compressor) or an impeller (centrifugal compressor). While the thermodynamic cycle is the same for both types of compression, the kinematic considerations, particularly with regard to the refrigerant used, are markedly dif-

Fig. 2—Brake Hp. in Ammonia System
(Both from H. J. Macintire's

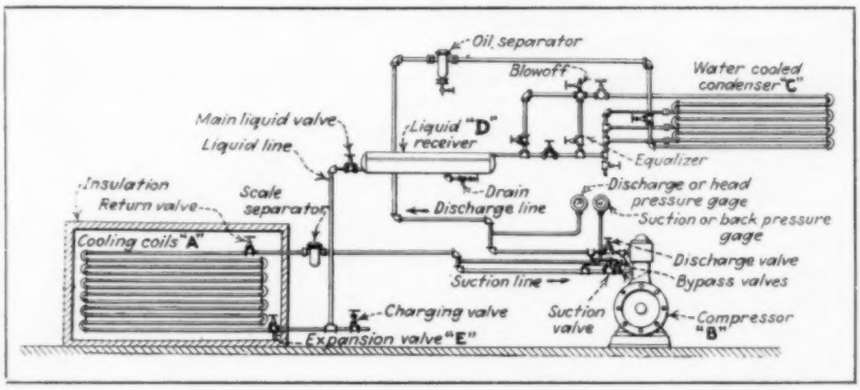


Condensed version of a chapter on refrigeration to appear in the forthcoming "Chemical Engineer's Handbook," published by McGraw-Hill Book Co., under the editorship of Dr. J. H. Perry.

APPLIED TO

MODERN INDUSTRY

Fig. 1—Simple Compression Refrigeration System Described in Text in Adjoining Column



ferent. The dense-air machine operates on the Carnot cycle and the vapor compression machine on the reversed Rankine (steam-engine) cycle.

Absorption systems differ essentially from compression systems in requiring no positive work input to produce cold, though generally requiring some accessory power. Circulation is effected by absorption of the refrigerant in appropriate liquids or solids which are regenerated by heat in another part of the refrigerating system. Absorption machines are classified as continuous or intermittent, the latter corresponding quite closely to batch processes. All continuous machines use liquid absorbents because of the great practical difficulties in moving a solid absorbent about from the absorption side to the generator. When continuous refrigeration is required with intermittent units, two or more machines must be installed.

Adsorption systems have a cycle of operation identical with that of the compression system with the exception that the compressor is replaced by a material, such as silica gel, which draws into its pores the refrigerant vapor coming from the evaporator and discharges the vapor at the condenser pressure upon the application of heat.

Evaporation cycles are those wherein water or, for that matter, other cheap fluids are evaporated at a reduction in pressure. The evaporation is at the expense of the heat in the remaining liquid, which as a consequence suffers a decrease in temperature.

This classification is neither absolute nor all-inclusive. Combinations of absorption and compression systems have been developed (Westinghouse-Leblanc). The processes for manufacturing liquid air, or solid carbon dioxide, do not fall into the above scheme, since they employ compression but do not recirculate the refrigerant. The distinctions are useful, however, in considering the operations involved.

Practically, mechanical refrigeration is the most important branch of the art and developments have centered almost wholly about the vapor-compression machine. The absorption machine was quite popular up to 1913 but is now gradually being superseded, and at the present time research has practically ceased in this field, except with respect to the small automatic gas-fired household machine.

A diagrammatic representation of a simple compression system of refrigeration is shown in Fig. 1. Refrigerant vapor is drawn from the expansion coil A at the pressure p_1 by the compressor B; forced into the condenser C at a pressure p_2, dependent on the temperature of the cooling water, where the vapor liquefies; and collected in the receiver D, from which it returns through the expansion valve E, under the pressure difference $p_2 - p_1$ into the expansion coil.

In this process the following heat quantities are involved, which may be taken from the tables of thermodynamic properties:

H_b = heat content of vapor leaving evaporator;

H_c = heat content of vapor leaving compressor;

h_e = heat content of liquid entering evaporator.

If the compression is adiabatic (isentropic) the work expended is $H_c - H_b$.

The net heat abstracted is $H_b - h_e$. Note that this is the heat of evaporation less the heat required to cool the liquid refrigerant from the temperature of the receiver to the temperature of the expansion coil. The ratio of the net heat abstracted to the work expended is known as the performance coefficient B and may be written

$$B = \frac{H_b - h_e}{H_c - H_b}$$

The inverse of this ratio is the efficiency coefficient E of the simple steam engine or turbine.

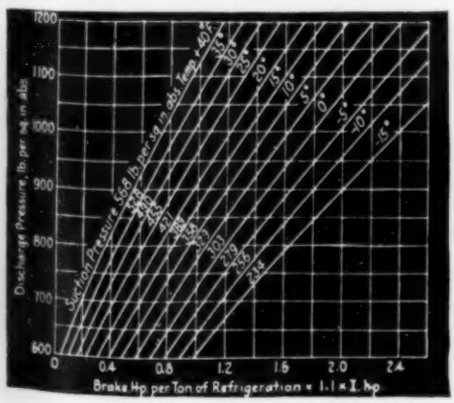
Performance Characteristics

Since refrigeration involves a conversion of work into heat, it might appear that the performance coefficient is dependent only on the temperature difference and is independent of the refrigerant used. This is only approximately true, as shown by Table I. The temperature difference, however, is important, and consequently a machine tested according to the standard American temperature interval (5 to 85 deg. F.) will show much better performance when tested on the British standard (23 to 59 deg. F.).

In Table II are the theoretical performance coefficients for ammonia, which will be found to hold approximately for all other refrigerants except those boiling much below ammonia. Carbon dioxide, the notable exception, will require a greater power expenditure. The brake horsepower, arbitrarily taken as 10 per cent greater than the theoretical, is shown in Figs. 2 and 3.

While the performance coefficients of

Fig. 3—Brake Hp. in CO_2 System
("Handbook of Mechanical Refrigeration")



refrigerants having critical temperatures well above that of the available cooling water will be approximately equal for a given temperature interval, the degrees of superheating will vary greatly.

The compression ratio $\frac{p_2}{p_1}$, which is determined by the latent heats, will be nearly the same for all refrigerants (*Trouton's law*), while the specific heat ratio will be smallest for those refrigerants having high molal heat capacities. The refrigerants having complex molecules will therefore have a much smaller temperature rise in adiabatic compression than those having simple molecules. In the case of ethyl ether ($C_4H_{10}O$) there is actually no superheating, but supercooling and liquefaction, while ammonia (NH_3) and sulphur dioxide (SO_2) give the greatest superheating on compression.

Table I—Comparison of Refrigerants

(One-ton refrigeration, 5—86°F.)

Cycle	Weight, Lb. Per Min.	Volume, Cu.Ft. Per Min.	Ratio of Compression	Coefficient of Performance	Horsepower	Relative Efficiencies
Ideal	.....	.....	....	5.74	0.8214	100
Ammonia	0.4214	3.44	4.93	4.85	0.973	84.5
Propane	1.396	3.35	3.64	4.88	0.9668	85
Carbon dioxide	3.74	0.999	3.11	2.56	1.843	44.6
Sulphur dioxide	1.388	9.24	5.63	4.735	0.995	82.5
Ethyl ether	1.555	60.8	7.12	4.86	0.971	84.6
Dichloroethylene	1.768	108.4	8.23	5.14	0.918	89.4
Trichloroethylene	2.137	513	10.84	5.085	0.928	88.5
Water	0.1996	1972	21.9	4.1	1.15	71.5

Carrier and Waterfill, *Refrigerating Eng.*, Vol. 10, 415, 1923.

Table II—Theoretical Horse Power to Produce 1 Ton of Refrigeration

Suction Pressure (Gage) and Corresponding Lb. per Sq.In.,	Temperature Deg. Fahr.,	Condenser Pressure (Lb. per Sq.In. Gage) and Corresponding Temperatures, (Deg. Fahr.)							
		103	115	127	139	153	168	184	200	218
P	T	(65°)	(70°)	(75°)	(80°)	(85°)	(90°)	(95°)	(100°)	(105°)
4	—20	1.058	1.130	1.205	1.283	1.361	1.443	1.525	1.609	1.691
6	—15	0.997	1.069	1.145	1.222	1.300	1.410	1.461	1.546	1.630
9	—10	0.903	0.978	1.045	1.118	1.193	1.260	1.347	1.435	1.509
13	— 5	0.818	0.883	0.954	1.023	1.094	1.168	1.244	1.321	1.396
16	0	0.735	0.801	0.865	0.933	1.002	1.072	1.147	1.219	1.255
20	5	0.666	0.731	0.795	0.859	0.928	0.998	1.066	1.138	1.212
24	10	0.592	0.663	0.726	0.789	0.854	0.921	0.991	1.060	1.129
28	15	0.541	0.600	0.664	0.728	0.792	0.855	0.922	0.994	1.060
33	20	0.474	0.534	0.592	0.672	0.715	0.780	0.842	0.903	0.974
39	25	0.410	0.466	0.523	0.580	0.599	0.702	0.767	0.829	0.892
45	30	0.351	0.406	0.461	0.518	0.576	0.635	0.694	0.759	0.817
51	35	0.300	0.355	0.410	0.467	0.521	0.580	0.640	0.701	0.763

Marks, Mechanical Engineers' Handbook.

Choice of Refrigerant

The choice of a material is always determined by the specific conditions of refrigeration to be met. In vapor-compression machines the work input required to abstract a given quantity of heat is determined primarily by the temperature difference rather than by any specific properties of the working medium. A refrigerant cannot be used in such a machine, however, if the temperature of the available cooling water lies above the critical temperature of the refrigerant. The temperature of cooling waters in America usually are too high to use carbon dioxide to advantage. In centrifugal compression machines it is necessary that the vapor pressures be as low as possible so as to reduce the number of stages and that the molecular weight be as high as possible so as to reduce the peripheral velocities of the impeller.

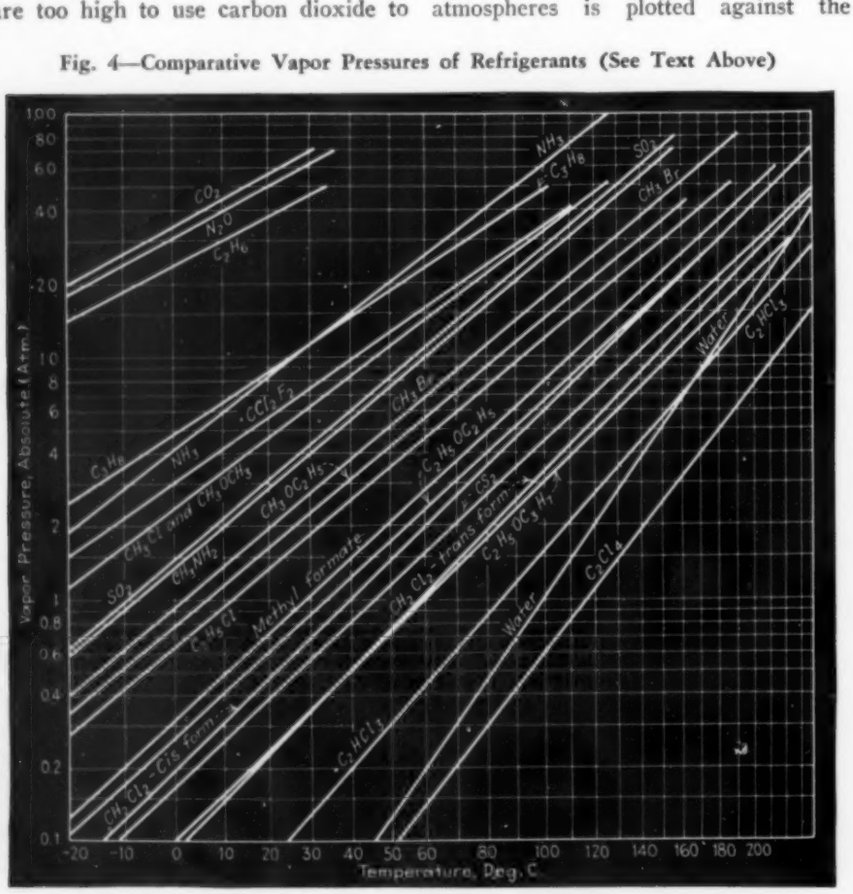
In vapor compression machines of the reciprocating type, refrigerants of high vapor pressure are desired, since these give low piston displacement and smaller friction losses. A comparison of the vapor pressures of various materials is shown in Fig. 4 where the logarithm of the vapor pressure in atmospheres is plotted against the reciprocal of the absolute Centigrade temperature.

Other properties of importance are: chemical stability, inertness to metals, ease of detection in case of leaks, and slight solvent action on lubricants. Cheapness is a very important item in larger units, since it is not practicable to prevent leakage altogether.

Ammonia is the most important refrigerant used in industrial work, but the irritating and toxic character of the vapors exclude it from certain applications, such as marine refrigeration or air-conditioning, where carbon dioxide is preferred when a reciprocating compressor is used. In certain chemical processes also, notably those in which free chlorine or other acidic gases may be present, ammonia is undesirable. In such processes, propane, having nearly the same pressures as ammonia and lower chemical reactivity, may be substituted in machines designed for ammonia. For household refrigeration, air condensers are preferred because of the convenience in moving the units about, and since ammonia does not work satisfactorily with an air condenser, it is not used in any of the small machines of the vapor compression type, its use in this field being confined to the gas-fired absorption machines.

The most important refrigerants used in household machines are sulphur dioxide and methyl chloride, though isobutane, ethyl chloride, and difluordichlormethane are used in some units. The last-named refrigerant has been developed in response to the demand for a non-toxic, non-inflammable material for household machines. Dimethyl ether, first proposed by Linde at the beginning of the modern period of refrigeration, is used in some German units. The low-pressure, high molecular weight refrigerants, trichlorethylene, tetrachlorethylene and methylene chloride, are used in centrifugal compressors for air-conditioning work.

Fig. 4—Comparative Vapor Pressures of Refrigerants (See Text Above)



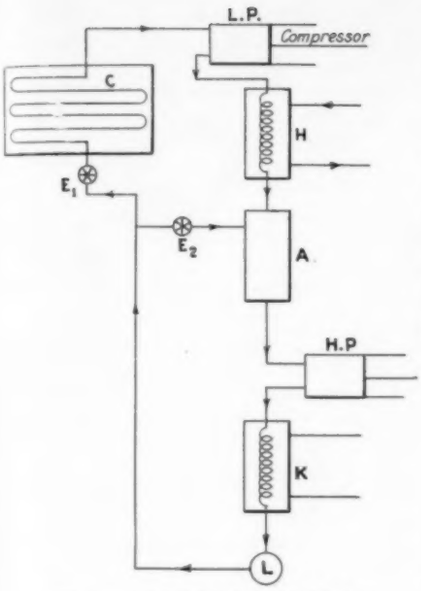


Fig. 5—Combination Multiple-Compression System

Binary mixtures have been proposed as refrigerating fluids, but they have been unsuccessful because one of the components is always likely to leak out more rapidly than the other, and when this happens it becomes impossible to interpret indicated pressures satisfactorily. They also require a greater work expenditure if any rectification occurs in the evaporator. If two refrigerants have nearly identical vapor pressures, such as methyl chloride and dimethyl ether, or carbon dioxide and nitrous oxide, they cannot be separated and would act as a one-component fluid. Two refrigerants may also form constant boiling mixtures which behave similarly, but the vapor pressures of such binaries have not been determined. There are no essential advantages in binary mixtures except that the freezing points might be lowered.

The heat-transfer characteristics of refrigerants, both in the liquid and gaseous phases, are also important, but very few comparative data have been obtained so far. According to R. C. Doremus (*Electric Refrigeration News*, Sept. 23, 1931), the rate of heat transfer for sulphur dioxide is about 85 per cent as great as for methyl chloride under the same conditions of evaporation. Thermal conductivities have been measured by Schreiber (*Z. Ver. deut. Ing.*, 75, 969, 1931), with the following results in B.t.u. per square foot per hour per degree Fahrenheit per foot: SO_2, 0.194; CO_2, 0.121; NH_3, 0.36 (approx.); H_2O, 0.36.

Multiple Compression Systems

When two refrigerating temperatures are required, the dual compression system may be employed. The general principle of this design is to draw in the vapor from the low-pressure (low-temperature) expansion coils, and at or near the end of the stroke, vapor from the higher pressure coils is admitted. The whole mixture is compressed to the saturation pressure corresponding to the temperature of the condenser water.

The advantages of this system are the use of one condenser for the two cooling systems and a markedly higher capacity, since the low-pressure cooling unit requires much larger piston displacement than the higher pressure unit and the high-pressure vapor is compressed through a small pressure range. The chief disadvantage, though not serious, is the difficulty of obtaining continuous adjustment between the loads on the two systems.

Multiple-Stage Compression

The most promising developments toward diminishing the power requirements of refrigeration are along the lines of multiple-stage compression. This principle has long been used in air compression, but in refrigeration the problem is more complicated. In general, it will prove economical with ammonia only where suction pressures lower than 5 lb. per square inch (gage) are encountered. As in the case of wet compression, it can be applied only to those refrigerants which superheat markedly on adiabatic compression (ammonia, sulphur dioxide, carbon dioxide; but not ethyl ether, F-12, propane, or butane).

Several possibilities in multiple compression are presented. First, the vapor from the first stage may be cooled by water in a heat exchanger before going to the second stage. Second, the vapor may be cooled by the liquid refrigerant, injected into the vapors from the first stage, to the temperature corresponding to the vapor pressure of the refrigerant equal to the pressure at the beginning of the second stage. Third, a combination of both may be used. A diagrammatic sketch of this third plan is shown in Fig. 5.

Vapor is pumped from the expansion coils *C* by low-pressure compressor *LP* into the heat exchanger *H*, where it is cooled by water. From *H* it passes into the accumulator *A*, where it meets liquid refrigerant from the liquid receiver *L*, which cools the vapor further. The high-pressure compressor then compresses the vapor to the saturation pressure of the condenser *K*, in which it liquefies and is collected by the liquid receiver *L*. The liquid refrigerant then returns to the expansion coils through the valve E_1 and to the accumulator through the valve E_2.

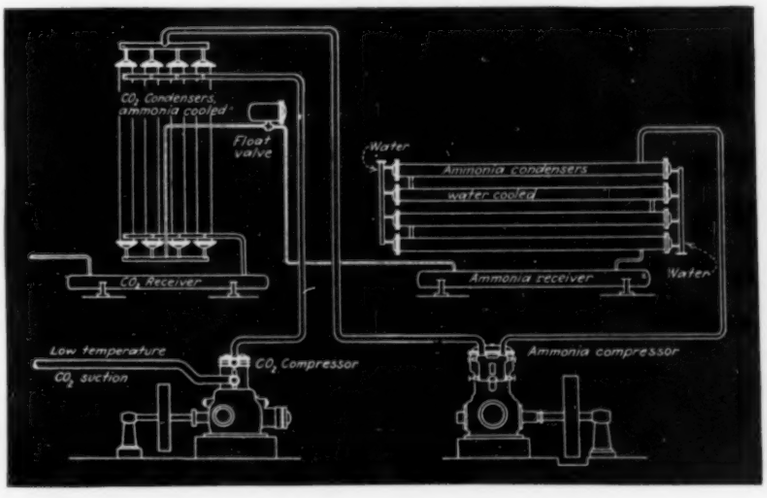
When ammonia is used for low-temperature cooling, a booster compressor is generally used to raise the low-pressure vapor to some intermediate pressure. The vapors are cooled before going to the high-pressure compressor, partly to save power, partly to take out the superheat which would continue to build up in the second compressor. A further advantage is the saving in cylinder volume.

Split Stage System

In the production of very low temperatures, carbon dioxide has the advantage of operating under positive gage pressures, whereas most other refrigerants operate with a vacuum, but the disadvantage of requiring very high pressures in the condenser. This difficulty may be overcome by using an ammonia compression system for cooling the carbon dioxide condenser with liquid ammonia. When ammonia alone with a booster compressor is used for low-temperature work, air may be drawn into the system, but it is more efficient in power expenditure than the split-stage or two-refrigerant system. Care must be exercised to make all joints tight in the two-refrigerant system, since ammonia and carbon dioxide react vigorously.

The conditions of operation found most practicable are: An ammonia suction pressure of 10 to 20 lb./sq.in. corresponding to —8 to +5 deg. F.; and a carbon dioxide condensing pressure of 300 to 375 lb./sq.in. (Kitzmiller, *Power* 75, 92, 1932). Carbon dioxide temperatures lower than —62 deg. F. may give trouble from snowing. Am-

Fig. 6—Split Stage System for Ammonia and CO_2



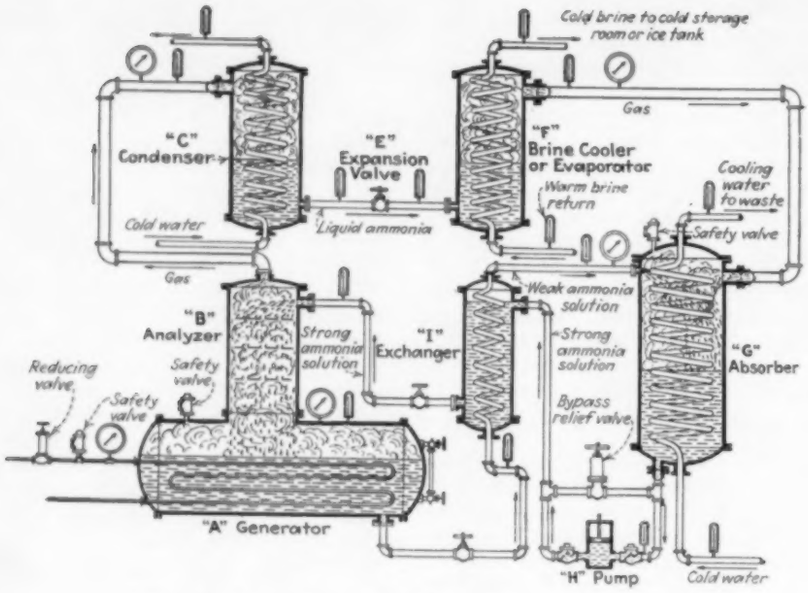


Fig. 7—Conventional Continuous-Absorption System

monia (—108 deg. F.) or methyl chloride (—153 deg. F.) give no difficulties from freezing. A diagram of a CO_2 — NH_3 system is shown in Fig. 6.

Continuous Absorption System

In the conventional continuous absorption system (Fig. 7) the refrigerant, usually ammonia, is drawn from the expansion coils F, at a given pressure p_1, and dissolved in the absorber G, where the combined pressure of solvent and refrigerant must be less than p_1. The refrigerant is recovered by applying heat to the generator A, separated from entrained water by the analyzer or rectifier B, liquefied in the condenser C, collected in a liquid receiver D (not shown), and returned to the expansion coils F through the expansion valve E. Since the absorber is at lower pressure than the generator, it is necessary to insert between them a pump, H, to transfer the ammonia solution, usually known as strong aqua. The generator does not remove all the ammonia from the water, and this weak aqua solution is returned to the absorber through the heat exchanger I. Considerable heat is evolved in the absorption of ammonia vapor, and cooling water must be supplied to keep down the temperature and pressure. In the absorption system two complete cycles are in operation: namely (1) the refrigerant cycle, and (2) the absorbent cycle. Just as the absorbent contains some ammonia, so the refrigerant contains a small quantity of water.

In the absorption cycle the heat quantities involved per pound of ammonia passing through the expansion valves are:

Q_1 = heat input to the generator;
Q_2 = heat absorbed by the expansion coils;
Q_3 = heat equivalent of the work of the pump;
Q_4 = heat rejected in the condenser;
Q_5 = heat rejected in the absorber;
Q_6 = heat lost by radiation, etc.

The heat balance is then given by the equation $Q_1 + Q_2 + Q_3 = Q_4 + Q_5 + Q_6$.

Of these quantities only Q_2, Q_3, and Q_4 can be computed with any exactness; Q_2 is very nearly the heat of evaporation of 1 lb. of ammonia at the temperature of the expansion coils. Similarly, Q_4 is very nearly the heat of condensation of 1 lb. of ammonia at the temperature of the condenser. Q_3 may be found by the equation $Q_3 = Gv(p_2 - p_1)$; where

G = pounds strong aqua pumped per pound of refrigerant passed,
v = volume of 1 lb. strong aqua in cu.ft.;
p_2 = generator pressure in lb. per sq.in.;
p_1 = absorber pressure in lb. per sq.in.

The heat rejected in the absorber Q_5 is made up of three parts: (1) the heat of condensation; (2) the heat of solution in going from weak aqua to strong aqua; and (3) the heat which must be removed from the weak aqua solution to reduce it to the temperature of the absorber. The theoretical heat input to the generator Q_1 has three corresponding parts.

In view of the lack of thermal data on the processes in the absorption machine, it is practically impossible to calculate efficiencies.

Absorption machines are gradually becoming obsolete in industrial work where they were formerly much favored for low temperatures. This obsolescence may be traced to several causes: (1) bulkiness of the apparatus; (2) increasing availability of cheap electric power; (3) development of multi-stage compression for low-temperature refrigeration; (4) lack of flexibility in its operation; (5) necessity of constant and skillful attention for maximum economy; (6) corrosion of the system by the aqua ammonia solutions, which, however, may be largely nullified by sodium bichromate to the extent of 0.2 per cent of the total aqua charge.

In the Platen-Munters continuous absorption system, circulation of refrigerant and absorbent is effected by the operation of hydrostatic forces developed within the system itself, and consequently there are no mechanical moving parts. In order to produce these hydrostatic forces, it is necessary to add a third component, which must differ in density (molecular weight) from the refrigerant and be capable of separation from the refrigerant. The usual combination is ammonia, water, and hydrogen, but a great many others are available.

In the intermittent adsorption machine the absorber and generator and the condenser and the evaporator are combined. During the cooling period, the refrigerant is taken up by the absorbent, which may be silica gel, activated charcoal, or chlorides of the alkaline earth metals. When the absorbent has become saturated, it is regenerated by heating and the vapors condensed in the evaporator, which is cooled by running water.

For air-conditioning work adsorption machines have recently acquired some promise, silica gel being used for adsorbing moisture from the air and later regenerated by gas-firing. A good deal of research is also being expended on their adaptation to truck and railway refrigeration (Keyes, *Ind. Eng. Chem.* 21, 477, 1929).

Evaporation System

Water at 32 deg. F. boils when under a pressure lower than 0.18 in. of mercury. Such a low pressure may be obtained by ejecting high-pressure steam through a nozzle. Water vapor at low pressure may thus be sucked into the ejector, and the removal of the latent heat will cause the residual water to freeze. In effect, the high-pressure steam is used to compress the low-pressure water vapor to an intermediate pressure, determined by the available cooling water, the ejector combining the functions of a steam engine and a vapor compressor.

In place of water, a brine may be used. The system can be adapted to permit the evaporation of the water and the deposit of the salt crystals.

Experiments are being conducted on a modification of this system, wherein a brine is pumped into the head of a barometric condenser. In dropping down the tail pipe the brine reduces the pressure in the condenser head and consequently the temperature. It is claimed that ice crystals may be formed through this action.

While the custom is either to freeze ice, which is later used for cooling, or to cool the chemical in a cooler in

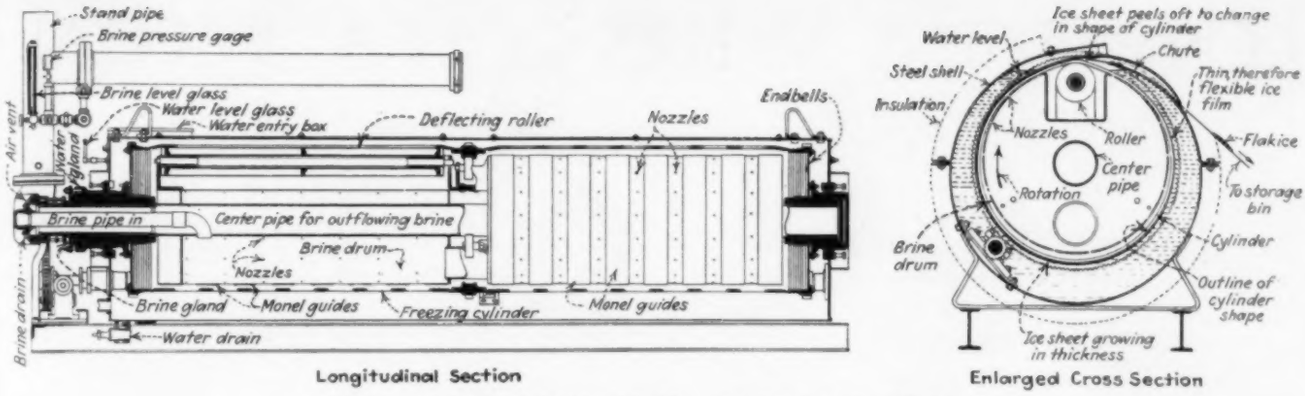


Fig. 8—Sections of Flakice Machine, Described in Text Below

which the refrigerant evaporates, various modifications are employed.

Flaked Ice

Can ice is slow to freeze after the initial half inch has formed, since the freezing time varies as the square of the thickness. Crosby Field (*Trans. Am. Inst. Chem. Eng.*, 24, 16-36, 1930) has developed a machine that forms ice (Flakice) in thin flakes which are then dislodged so that a new layer can form. This machine freezes ice in much the same way as in the plate system.

In Fig. 8, which is a sketch of the Flakice machine, a tank has a space between its outer walls and inner walls filled with granulated cork or other heat-insulating material. Mounted inside this tank is a flexible cylinder composed of thin, comparatively wide bands of non-corrodable material such as Mond 70, bound together by means of rubber strips. These strips are very narrow between panels, but extend farther into the interior of the cylinder. In addition to holding the metal bands together they have the function of providing an insulating space about the perimeters of the metal bands, forming a dividing belt marking off one dimension of the Flakice cake. The cylinder is held to rotating end bells at each end by means of rubber strips. A revolving shaft carrying one end bell is power-driven by a motor operating through a coupling, reducing gears, and a main gear. A jack shaft extends under the tank to the other end, where it carries a gear meshing with a similar set of gears, so that the end bells provide power to rotate the cylinder from both ends, preventing any twisting stress on it. The revolving shaft also carries a sprocket driving the conveyor shaft by means of a chain and sprocket.

In ice making, brine from a brine cooler flows through an inlet pipe and hollow shaft into the interior of the cylinder, where it is distributed through high-velocity nozzles along the revolving heat-transfer surfaces. This surface is kept running, submerged in water, maintained at the proper level by a float valve. The brine then flows out through the other end of the hollow shaft into a surge tank which maintains the proper static head of brine on the cylinder. It returns from the surge tank to the cooler through an outlet. The rotating cylinder soon freezes a thin cake of ice upon its exterior. An automatic mechanism within the cylinder causes rollers to press out against the cylinder. The ice thus cracked and peeled, floats on the top of the water level, where conveyor prongs skim it from the surface. It is dried while being carried on rods to a discharge chute, whence it falls into bin.

The effect of the size of the ice particles on the rapidity of temperature decrease is intimately connected with the surface area exposed per unit weight of ice. The standard cake of ice, weighing 300 lb. and having a latent cold value of 43,200 B.t.u. and dimensions 11x22x38 in., has a surface of about 20.7 sq.ft. The same weight of $\frac{1}{8}$-in. thick "Flakice" will have 1,000 sq.ft., or nearly 50 times the surface of the standard ice cake.

Another recent development in the manufacture of ice is the Pak-Ice machine (Fig. 9). A corrugated liner is fitted into an outer casing and liquid ammonia under a 4-ft. head is fed into the space between the two. The inside of the liner is filled with circulating water (18 ft. per second) which freezes rapidly on the liner surface to a thickness not over 0.008 in. and is constantly removed by tool scrapers. The ice scraped off the sides is driven toward the center and carried out of the machine in a stream of water, and transferred to a bin when the water is drained off. The machine may also be used to produce frozen brines.

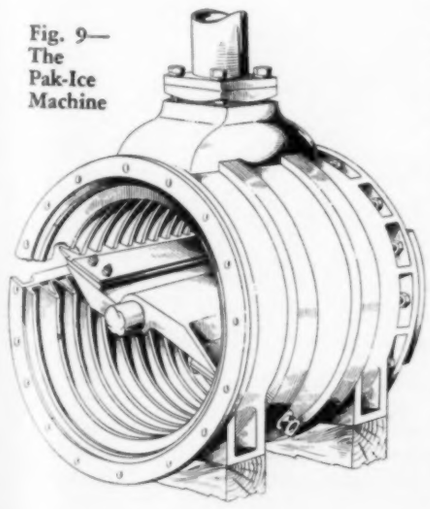


Fig. 9—The Pak-Ice Machine

The Pak-Ice machine can be employed to recover salts from solutions. For example, a glauber salt solution in passing through the machine will chill and deposit part of the salts. It is also possible to chill lubricating oil to a point where the wax will settle out, to be removed by the scraper.

Chemical Refrigeration

Water freezes at 32 deg. F. and, conversely, melts at this temperature. If sodium chloride be mixed with ice, the melting point is lowered and the mixture melts until the loss of heat by melting lowers the temperature to that corresponding to the melting point of the mixture. Absorption of heat from the outside induces a continued melting until the substance is all liquid, whereupon a further heat absorption causes the temperature of the solution to rise. This method of refrigeration is in common household use for making ice cream, by packing the can in a mixture of ice and salt, which melts at 0 to 20 deg. F. The melting points of mixtures of ice and different salts vary, the addition of potassium hydroxide to snow in a 4 to 3 ratio lowering the freezing point from 32 deg. F. to —38.3 deg. F.

Some of these freezing mixtures cannot be used commercially for refrigeration, but they are frequently of use in laboratory or other small-scale work. Mixtures of crushed ice, however, are extensively used for ice cream shipment or other foodstuffs requiring low temperatures. A common method of distributing ice cream is to charge cans with sodium chloride brine which is frozen solid. The ice cream container is then packed snugly in these frozen cans. Where crushed ice-salt mixtures are used, the salt is wasted, and the drippings cause considerable corrosion, particularly on rails under refrigerator cars. Several of the large ice cream manufacturers have accordingly replaced such mixtures with solid CO_2.

COMPARATIVE VALUES OF HEAT IN COAL, OIL AND GAS

By S. H. VIALL

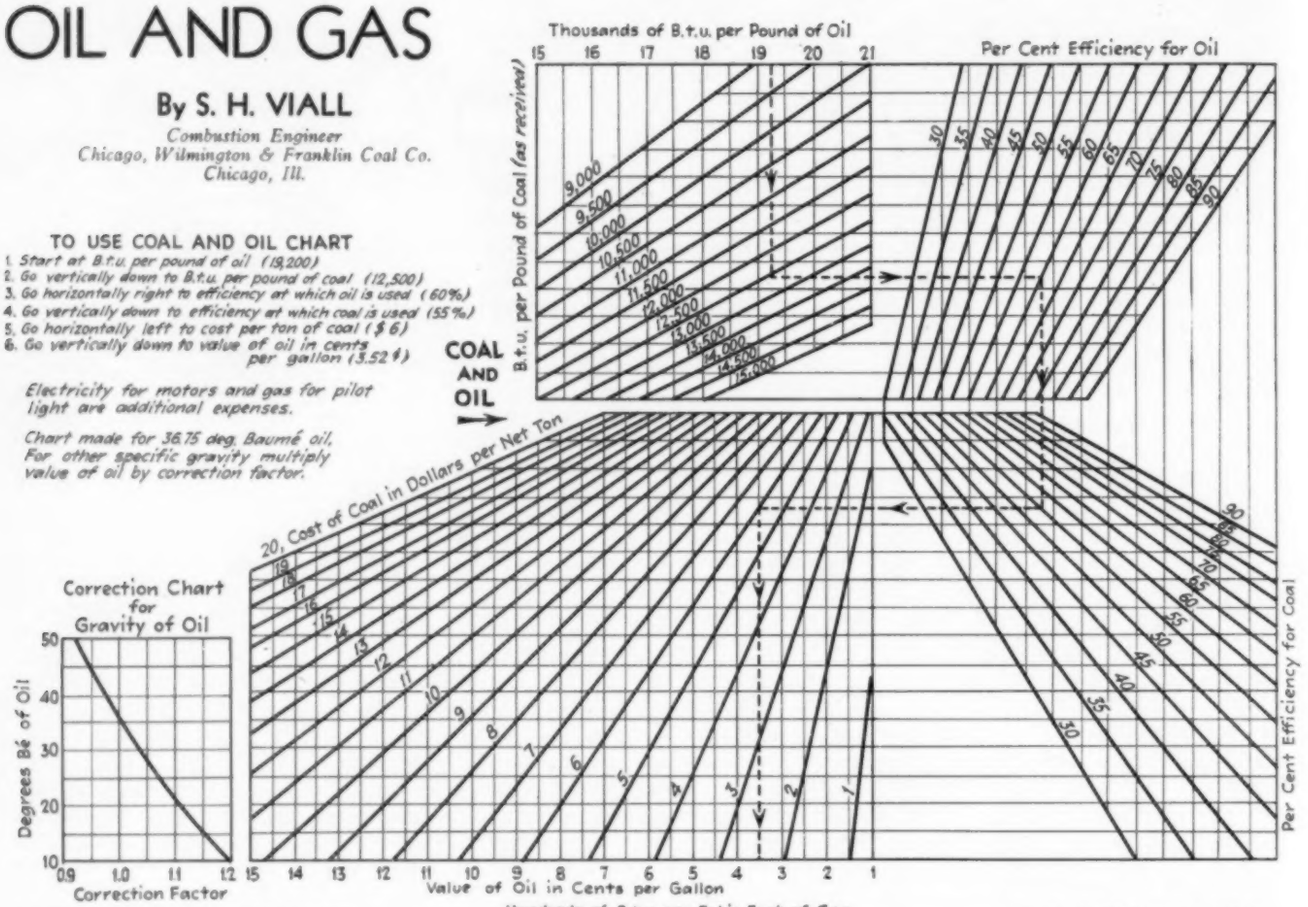
Combustion Engineer
Chicago, Wilmington & Franklin Coal Co.
Chicago, Ill.

TO USE COAL AND OIL CHART

1. Start at B.t.u. per pound of oil (19,200)
2. Go vertically down to B.t.u. per pound of coal (12,500)
3. Go horizontally right to efficiency at which oil is used (60%)
4. Go vertically down to efficiency at which coal is used (55%)
5. Go horizontally left to cost per ton of coal ($6)
6. Go vertically down to value of oil in cents per gallon (3.52¢)

Electricity for motors and gas for pilot light are additional expenses.

Chart made for 36.75 deg. Baumé oil. For other specific gravity multiply value of oil by correction factor.


Thousands of B.t.u. per Pound of Oil
15 16 17 18 19 20 21
Per Cent Efficiency for Oil
B.t.u. per Pound of Coal (as received)
9,000
9,500
10,000
10,500
11,000
11,500
12,000
12,500
13,000
13,500
14,000
14,500
15,000
30 35 40 45 50 55 60 65 70 75 80 85 90
COAL AND OIL
Cost of Coal in Dollars per Net Ton
20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
Per Cent Efficiency for Coal
Correction Chart for Gravity of Oil
Degrees Bé of Oil
50 40 30 20 10
0.9 1.0 1.1 1.2
Correction Factor
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
Value of Oil in Cents per Gallon

TO USE COAL AND GAS CHART

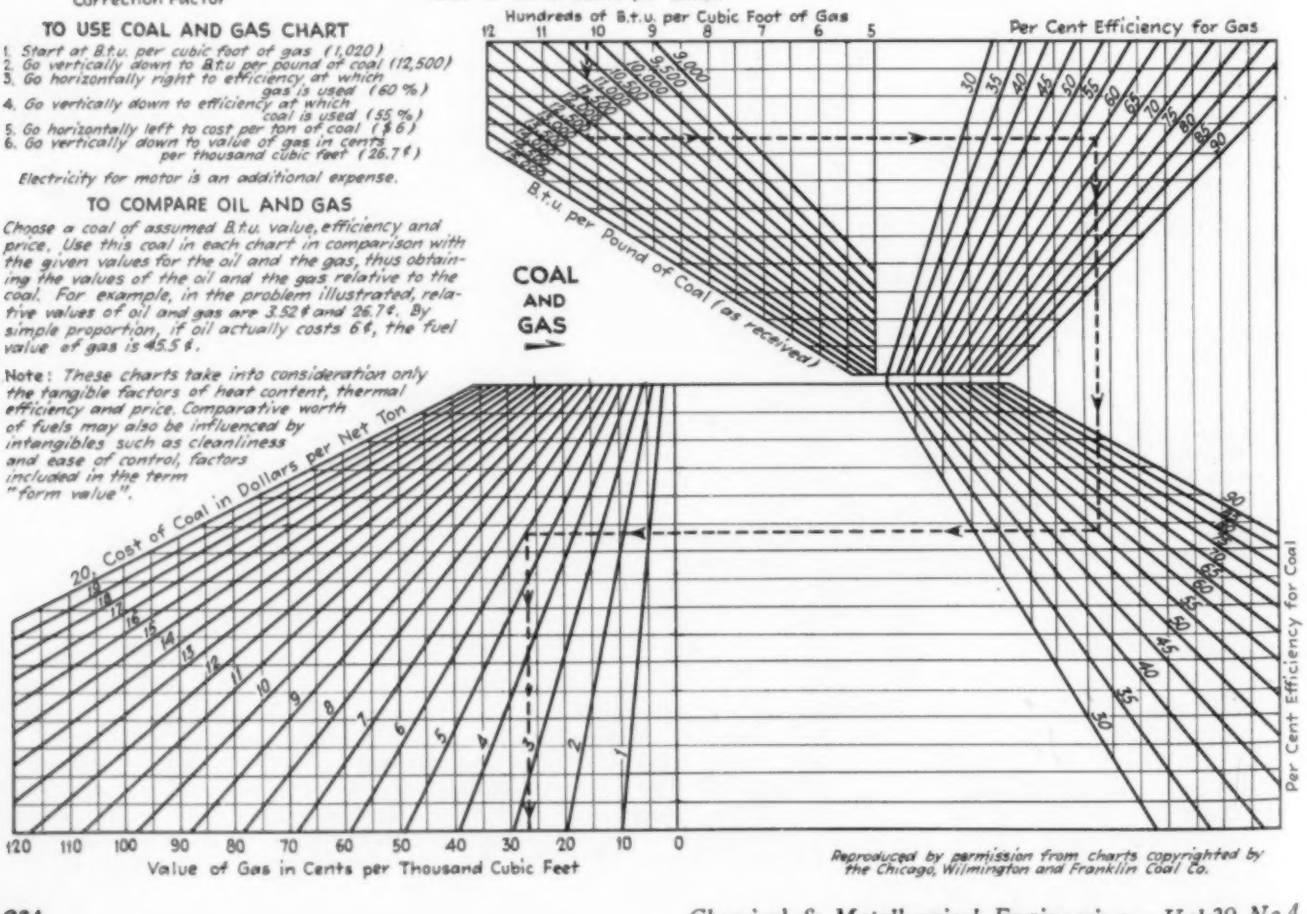
1. Start at B.t.u. per cubic foot of gas (1,020)
2. Go vertically down to B.t.u per pound of coal (12,500)
3. Go horizontally right to efficiency at which gas is used (60%)
4. Go vertically down to efficiency at which coal is used (55%)
5. Go horizontally left to cost per ton of coal ($6)
6. Go vertically down to value of gas in cents per thousand cubic feet (26.7¢)

Electricity for motor is an additional expense.

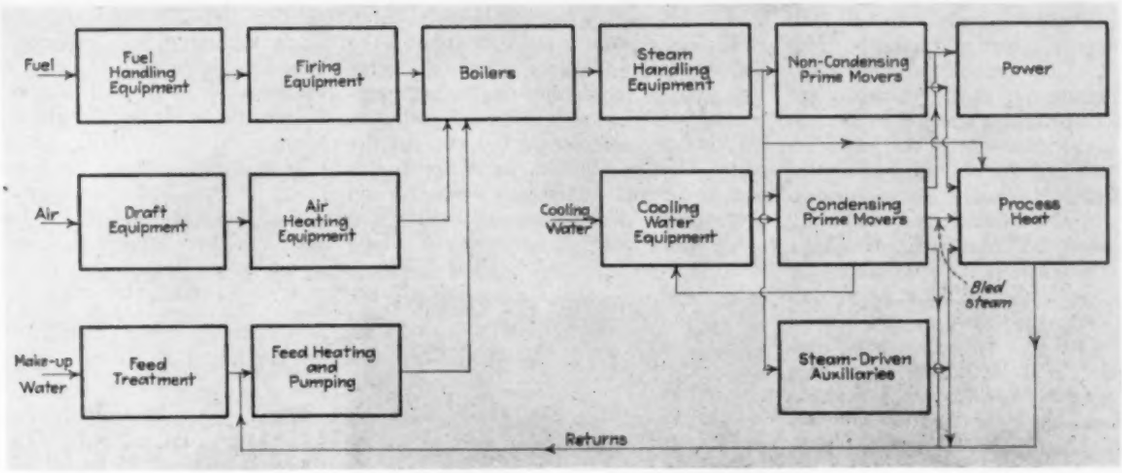
TO COMPARE OIL AND GAS

Choose a coal of assumed B.t.u. value, efficiency and price. Use this coal in each chart in comparison with the given values for the oil and the gas, thus obtaining the values of the oil and the gas relative to the coal. For example, in the problem illustrated, relative values of oil and gas are 3.52¢ and 26.7¢. By simple proportion, if oil actually costs 6¢, the fuel value of gas is 45.5¢.

Note: *These charts take into consideration only the tangible factors of heat content, thermal efficiency and price. Comparative worth of fuels may also be influenced by intangibles such as cleanliness and ease of control, factors included in the term "form value".*


Hundreds of B.t.u. per Cubic Foot of Gas
12 11 10 9 8 7 6 5
Per Cent Efficiency for Gas
B.t.u. per Pound of Coal (as received)
9,000
9,500
10,000
10,500
11,000
11,500
12,000
12,500
13,000
13,500
14,000
14,500
15,000
30 35 40 45 50 55 60 65 70 75 80 85 90
COAL AND GAS
Cost of Coal in Dollars per Net Ton
20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
Per Cent Efficiency for Coal
120 110 100 90 80 70 60 50 40 30 20 10 0
Value of Gas in Cents per Thousand Cubic Feet

Reproduced by permission from charts copyrighted by the Chicago, Wilmington and Franklin Coal Co.



WHAT'S IN THE INDUSTRIAL POWER PLANT AND WHY

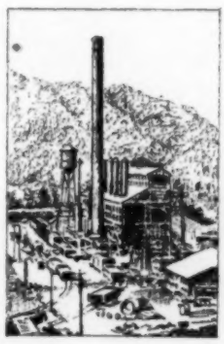
EDITORIAL STAFF

NOT ONLY because the power plant today needs the chemical engineer but, more particularly, because the chemical engineer needs the power plant, it is worth while to take a quick excursion through a composite, modern industrial station and familiarize ourselves with some of the more important of its newer developments and trends.

Primarily, the function of a steam generating station is to produce power or steam, or both, and to do it at the least possible cost. The power engineer cannot afford to overlook the fundamental dollar interest; in his effort to impound the last and most elusive B.t.u., he cannot forget its cost. In the final analysis he must balance heat recovery against operating expense, a balance which he has discovered varies widely with the type and purpose of the plant. Industrial practice, especially where there is a sizable process steam demand, differs materially from that of the central station, which, because of its enormous loss of heat to the condenser, can justify a much more costly and efficient recovery of heat than can the industrial plant.

For this reason, it is the exceptional industrial plant that can afford to go to pressures over 500-600 lb. and use the more highly refined and expensive methods of heat recovery. Only with a large and overbalancing power demand, or with special process requirements, is it possible to consider pressures over 600 lb. as economical in process plants. While this situation may eventually change, at the present stage, plant investment increases rather sharply at about 500 lb., and although it decreases from that point to 1,200-1,400 lb. pressure, even there the capital cost will be five or more per cent higher than for a plant of 500 lb. or less. Furthermore, only where fuel is exceptionally high in price can the byproduct-power-plant designer justify a degree of boiler efficiency approaching that now being obtained in the modern central station.

A boiler consumes three raw materials—water, fuel, and air—in turning out its single product, steam. It is a rare and fortunate plant in which some form of water treatment is not required. In general, aside from simple filtration, which ordinarily is used with some sort of additional treatment, there are two methods employed—chemical and evaporative. Internal treatment, once in the discard, has gained new importance through the phosphate method of recent years. Acid addition for the control of caustic embrittlement is increasingly practiced, particularly with zeolite-softened water. Where the problem is one of hardness of more than two or three grains per gallon of raw water, many plants use the lime-and-soda hot process, many others the zeolite, the latter, however, only in cases where the raw water is neither acid nor highly carbonate.



For waters which, either with or without treatment, tend to deposit sludge in the boiler, the old intermittent blow-down is giving way to the continuous-deconcentration method, using an external settling tank or filter through which the boiler water continuously circulates. In order to keep down the concentration of dissolved impurities, modern installations are employing the method of continuous blow-down in which a small percentage of the boiler contents is continuously bled off to waste through one or two heat ex-

changers in which it gives up its heat to incoming feed water.

These various methods are generally sufficient in lower-pressure plants. Once a plant goes to high pressure, even non-scaling impurities must be removed. For this reason, the make-up is almost always distilled, usually after chemical softening; and all boiler feed, including returns, must be de-aerated. Neither of these operations is particularly costly from a thermal point of view, since each returns the greater part of the heat it uses to the boiler. The evaporator uses bled steam and feeds the vaporized make-up water into the system, perhaps in a de-aerating heater which consists simply of a vented tank supplied with return condensate through which steam is bubbled to remove dissolved air and other gases.

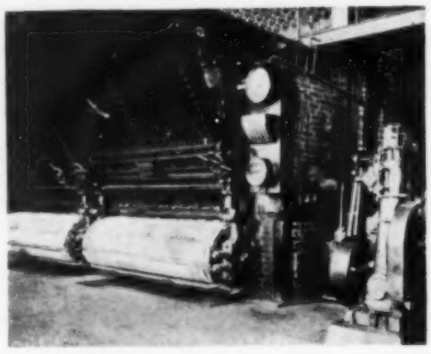
Fuel Preparation and Stoking

Fuel supply is perhaps a less complicated problem than water make-up, but it will nevertheless introduce variables into the design. Under special conditions, oil, manufactured and natural gas, producer and refinery gases,

Handling Coal to Coal Preparation Building in an Industrial Plant

and waste products such as coke breeze, petroleum coke, wood and bagasse may be burned. Oil and gas fuel introduce no particular complexities, being in fact much more easily handled than coal. Coke breeze and petroleum coke are readily burned in several types of stoker equipment or in a manner similar to powdered coal. Wood and bagasse require special furnace designs, usually of Dutch-oven construction with large grate area to overcome the effect of low calorific value.

Coal, of course, is the principal fuel. In plants of any size it is now being burned on stokers or in pulverized form. But first, it must be brought to the boilers. If space is available for outside storage, locomotive-crane and drag-bucket handling are the most common. To elevate and convey the coal to the plant storage, bucket and flight elevators, chain carriers, portable and permanent belt conveyors, and skip hoists are favorite equipment. Silo

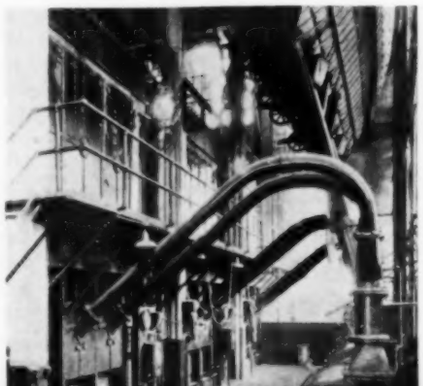


Steam-Engine-Driven Chain-Grate Stokers Firing Boilers

storage is sometimes employed, although the more usual method is to provide for several days' operation in overhead bunkers which run the length of the boiler room. From the bunkers, coal may be distributed to the stokers or pulverizers by means of individual spouts or by traveling larries, generally arranged to weigh, and sometimes to record, the coal charged to the individual boilers.

Pulverized coal has become very widely used in the last decade. It permits ready control, high furnace capacity and efficiency, and gives satisfactory results with a wide range of coals. Two methods are employed: the unit system, in which each boiler has its own pulverizer and air-conveying equipment; and the storage system, in which the pulverized coal is conveyed, usually pneumatically, to overhead storage from which it feeds to a number of furnaces. The unit system is generally better suited to industrial plants because of its flexibility, low first cost, and small space requirement. It employs an air-swept mill with integral or separate conveying-air fan and may use drying air heated either in the boiler or in a steam heater. The storage system may be required on account of high peak loads or because the pulverizers must be located in a separate building. It uses both air and screen separation and transports its product from the storage hopper to the furnaces either pneumatically or with a solids pump. Various sorts of pulverizers, including ball-and-race, ring-roll, tube, and impact mills, are used in both systems. Storage pulverizers may use a separate dryer, or drying may be accomplished in the mill. Coal in either case is introduced into the furnace vertically, inclined to the horizontal, or horizontally, a variation of the latter being the method of tangential firing from the four corners of a square furnace, which is said to promote turbulence and assure a high combustion rate.

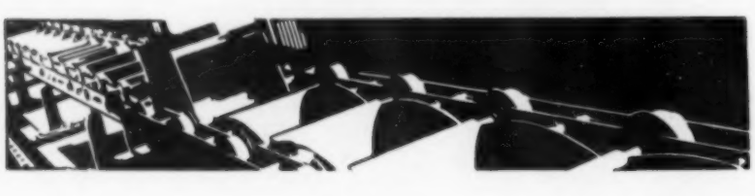
When coal is stoker-fired, the stoker must be adapted to the coal. Stokers are of three general types. The chain grate, using a horizontal, traveling bed to convey coal across the combustion space, is particularly suited to low-grade and high-volatile coals, as well as to anthracite and very fine combustible materials. The overfeed stoker introduces coal at the upper end of an inclined grate which has some sort of reciprocating motion to carry fuel downward to the ash discharge. Caking coals are well handled with this type. The underfeed stoker completes the list. Coal is pushed by rams into one or more "retorts," from which it feeds upward through the fuel bed, giving volatile matter an opportunity to distill off before the coal reaches the surface. Such stokers may be horizontal or they may slope downward to the ash discharge. They have high capacity and are well



Unit Pulverizers for Powdered Coal, Firing Cross-Drum Boilers

suited to a wide variety of coals, including those that tend to coke in the furnace.

In any event, some method of ash removal must be used. Frequently the stoker discharges through crushing rolls which feed the crushed clinker into a storage hopper beneath the furnace. Many plants remove the clinker by gravity to conveying apparatus such as cars or chain carriers. Pulverized-coal plants, as well as stoker-fired plants,



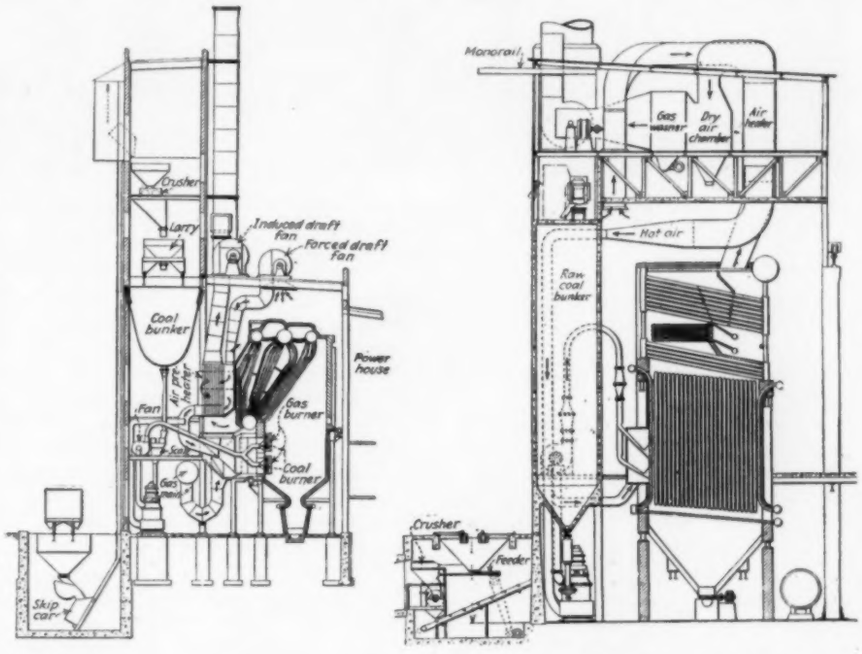
frequently sluice ash from the pit with a jet of high-velocity water. The method being practiced in some of the more modern installations is to tap off the molten slag into a water bath, or to break it into small pellets with a water jet, and discharge it to a sump from which it is conveyed to cars by crane equipment.

Air is the third and last raw material of steam generation. In moderate-sized and large installations, especially if fuel cost is not extremely low, preheating of the air is generally used to increase the furnace temperature and recover heat from the flue gases. Air heaters are of three types, including various forms of tube or plate heat exchangers and regenerative heaters. In the first two types, heat transfer takes place through a separating metal wall. In the third, a rotating, cellular disk stores heat in contact with the flue gases as they pass through half its area. As the disk rotates, it gives off its heat to incoming cold air which is passing through the other half of the cellular structure.

To avoid excessive stack size and permit high combustion rates, moderate- and large-sized plants invariably employ forced or induced draft or both. The additional resistance introduced by stokers, economizers and air preheaters makes fan handling of the air or of the combustion gases necessary as a matter of course. Forced draft alone puts the furnace under pressure, and induced draft, under suction. Higher ratings require balanced pressure that is possible only when both forms of draft are employed simultaneously. In stoker installations primary air is introduced through perforations in the grates, while secondary air may be admitted at other points. With pulverized fuel, air is supplied in part as conveying air and, secondarily, as a blast adjacent to or surrounding the fuel jet.

Furnaces and Boilers

We now come to the heart of the plant, the boiler itself. Boilers and boiler furnaces have undergone startling changes in recent years. For stationary power purposes, the old fire-tube boiler, chiefly exemplified by the horizontal-return-tubular boiler, is now of little importance. Even the old-style, single-drum, water-tube boiler has been metamorphosed, and the multi-drum boiler has come into its own. Boilers no longer operate in the conservative manner of 50 years ago. Overloads as high as 700 or 800 per cent are not uncommon. This has required two very significant improvements in design: better circulation and the water-cooled furnace. Improved combustion equipment has decreased the excess air required, and this, combined with the high heat-liberation rates now in use—as high as 30,000 to 50,000 B.t.u. per cubic foot of furnace volume per hour—has forced the furnace designer to find a substitute for refractory furnace walls. Air-cooled refractory walls have sufficed for lower ratings, but partial or complete lining of the furnace space with water-filled tubes or water-cooled refractory blocks, connected into the boiler circulatory system, has been found necessary in high-capacity, high-efficiency equipment using preheated air. Water walls may be composed of bare tubes, of tubes protected with plastic refractory or refractory blocks, or with cast iron blocks clamped, welded, cast or shrunk onto the tubes. Powdered coal furnaces generally add a tube screen to the top and bottom of the furnace space, the upper screen helping to retain fly ash in the furnace, the bottom cooling the molten ash particles as they settle to the floor.



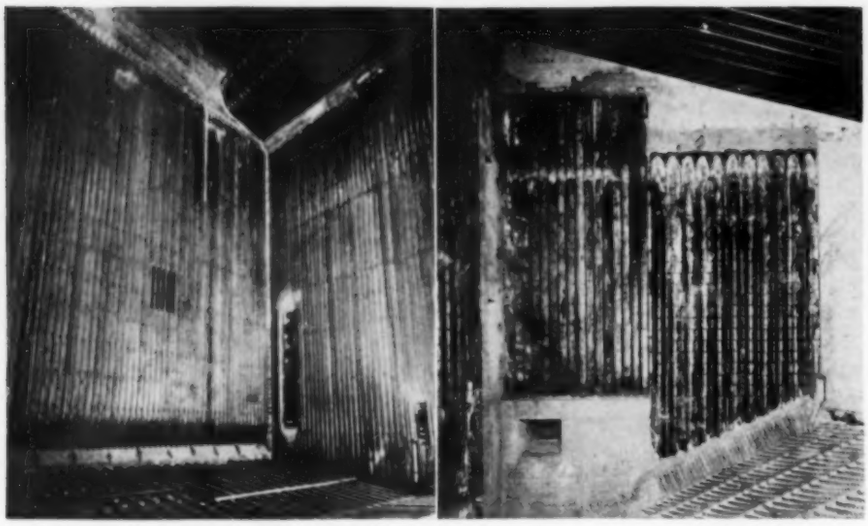
Cross-Section at Left Represents a Typical Industrial-Plant Boiler Room Equipped With Four-Drum Boilers With Water Walls, Fired With Both Coal and Blast-Furnace Gas. At the Right Is a Water-Wall Cross-Drum Boiler With Pulverized-Coal Firing and Air Preheating. Plant at Left Uses a Skip Hoist, While That at Right Uses Belts and Elevator for Raw-Coal Handling

Although it was not the original intention to use the water wall for steam generation, it has been found that the large surface which it presents to radiation actually evaporates a considerable part of the total boiler output. In fact, furnaces are now being built in which practically all of the evaporation takes place in the wall and screen tubes. In one form, the true convection tubes serve only as an economizer. In another, even these tubes have been omitted and in their place the manufacturer has installed a steam reheater for re-superheating steam between the high- and low-pressure turbines.

Improved circulation at higher ratings has been attained in several ways. Water walls themselves are conducive to high circulation. In the case of horizontal-tube boilers, the longitudinal drum has largely been replaced by the single cross drum which gives high strength and reasonably good circulation. This form of boiler has been found suitable for all pressures up to the highest. For installations where maximum steaming rate is desired, bent-tube boilers utilizing three or four drums, or even more, have come into wide use. This construction is not as strong, inherently, as the straight-tube boiler, so that it is not used for the highest pressures. But by virtue of the nearly vertical position of the tubes, and the close approach to counterflow heat exchange possible with this form of boiler, its circulation is better than that of the cross-drum type, making it more suitable for large-capacity installations.

Types of Superheaters

Where steam is to be used for power production, either as byproduct power or as the sole product of the plant, all modern installations employ superheat, which is a necessity in turbine operation. Superheaters are of two general types, the integral and the separately fired. The former, which is most used, appears in two different forms, one being the convection heater, which consists of a group of tubes placed outside the combustion space, in the path of flue gas which has already made one pass, or part of a pass, through the boiler tubes. The second form, the radiant type of integral superheater, is installed in the furnace proper, in a manner similar to the water wall, or as part of the water wall, and is capable of producing higher steam temperatures than the convection type. With the convection superheater, steam temperature tends to rise at higher loads, while with the radiant form, it falls. To main-



Typical Water-Wall Furnaces, Showing at the Left, Bare-Tube Construction; at the Right, Protected Tubes; View at the Left Shows Bottom Screen Tubes, and at Right, Underfeed Stoker Retorts

tain a more nearly constant temperature, regardless of the load, some designers combine both radiant and convection surfaces, connected in series, in the one boiler.

Boiler efficiency is determined to a considerable extent by the treatment given the flue gas after it leaves the last boiler-tube bank. Increasing steam temperatures, with consequent higher stack temperatures, have revived interest in economizing and air-preheating. Many installations now use equipment for both purposes. Economizers are tubular heat exchangers used for heating the feed water before it enters the boiler. They receive the flue gas as it leaves the boiler, discharging it into the air preheater, if one is used, or to the stack. When an air preheater is used, its additional resistance usually requires that gas discharge through an induced-draft fan.

Boiler Auxiliaries

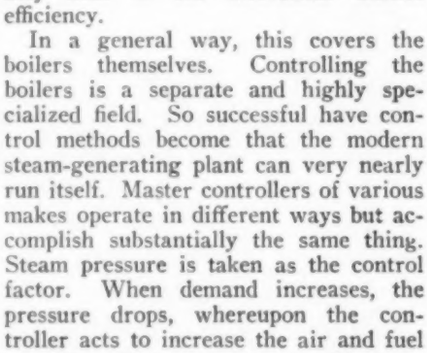
Much of the success of the modern boiler depends on its auxiliaries, some of which have already been mentioned. Smaller boilers often use the injector or the steam pump for boiler feeding. Larger plants have gone to plunger pumps or to the multi-stage centrifugal feed pump, which has attained a high degree of proficiency, both in the turbine- and motor-driven models.

Feed-water heating is another thing that has gone far in recent years. Originally it relied for its heat chiefly on the economizer and on exhaust steam from auxiliaries. The old open heater is still used with exhaust and other low-pressure steam, but the modern plant will often employ, in addition to an evaporator and a de-aerating heater, from one to four closed heaters operating on steam which is bled at one or more points from a moderate-pressure turbine, or which exhausts from a high-pressure turbine. Particularly in the higher-pressure plants, to a greater and greater extent the boiler is being relied upon to supply chiefly the latent heat of evaporation. As a consequence, boiler surface has decreased relatively, while heat-recovery surfaces, including the air preheater, the economizers, and the high- and low-pressure heaters, have enormously increased. Heating in closed heaters is carried out countercurrently and results in what is known as the regenerative cycle. It enables the prime mover-boiler cycle to approach reasonably near to the theoretical Carnot efficiency.

In a general way, this covers the boilers themselves. Controlling the boilers is a separate and highly specialized field. So successful have control methods become that the modern steam-generating plant can very nearly run itself. Master controllers of various makes operate in different ways but accomplish substantially the same thing. Steam pressure is taken as the control factor. When demand increases, the pressure drops, whereupon the controller acts to increase the air and fuel supplies. Most master controllers incorporate some form of anticipatory device which determines the rate of demand change and makes its corrections accordingly.

Feed water is controlled by separate equipment, either by the boiler level alone or by a combination of boiler level and steam-flow rate. Other boiler-room control includes equipment for the remote operation of principal valves and for the indicating or recording of boiler draft, steam-flow rate, water level, temperatures, pressures, smoke density and flue-gas composition. It is virtually possible for a single operator to check and, if need be, control the operation of an entire plant from a central control gallery.

High-Pressure Boiler Feed Pumps Direct-Connected to Motors



Auxiliary Steam Equipment

Occasionally the industrial plant will employ auxiliary steam-supply equipment. Where there are recurring peak loads, steam storage in an accumulator will often make it unnecessary to carry excessive standby boiler capacity. The accumulator is a device which condenses steam in superheated water, later releasing it upon reduction of the pressure. Where cheap dump power, usually from hydro plants, is available at intervals, plants occasionally find an auxiliary electric boiler to be an economy. Auxiliary steam generation in waste-heat boilers has been found profitable in certain installations for the burning of pyrites and in such works as cement and paper mills, gypsum, water-gas and coke plants. Some of the last-mentioned recover the heat in hot coke by circulating inert gas through it and cooling the gas in a waste-heat boiler. Plants using diesel engines as prime movers can often recover the exhaust heat advantageously in waste-heat boilers. The engine jacket water is sometimes circulated to process or other heating equipment.

When steam leaves the boiler it must be conveyed, with as little loss as possible, to the point of use. Since the advent of high-pressure generation, welding of pipe joints has become increasingly important in the power plant. Higher temperatures and pressures have forced the development of special materials for pipe and fittings, valves, gaskets and insulation. Forged steel valves and fittings, numerous new special joints, corrosion- and erosion-resisting metals, even seamless tubing, have all entered the power plant to stay.

In addition to piping, valves and fittings, the distribution system will often include steam flowmeters at various junction points in the system and such equipment as desuperheaters, moisture separators, reducing valves and means for removing condensation from the lines.

Desuperheating is accomplished by cooling the steam, either with a water spray or, indirectly, by contact with water-cooled surfaces. It may be practiced to supply saturated steam at boiler pressure, or for closer control of steam temperatures at reduced superheat. Moisture separators remove the water by centrifugal action, returning it by gravity to the boiler, or through a

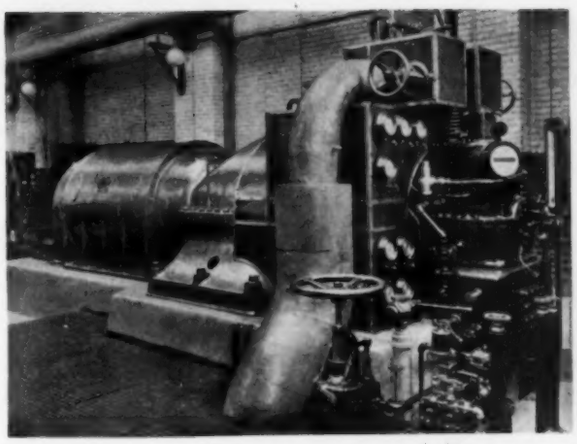
trap to the return system. Reducing valves are either of single- or balanced-disk construction and use the downstream pressure, acting on a diaphragm, to control the valve opening, either with or without the assistance of a pilot piston actuated by the upstream pressure. Condensation in the distribution system is drained at intervals to one or more common traps which may be either of the boiler-return type or may discharge to the main condensate return.

Prime Mover Equipment

When a process plant generates part or all of its own power, most of its steam will be piped to the prime movers. If the latter are used to generate electricity or operate other high-speed machines, they usually will be turbines, particularly in the newer plants. Turbines possess several advantages over engines. They can expand steam to much lower pressures, thus extracting more work per pound of steam supplied. They are inherently more flexible and more compact, and permit enormous capacity under close regulation. They introduce practically no oil into the exhaust steam, which is advantageous under any circumstance, but particularly so when the steam is to be delivered to process.

A turbine is essentially a machine for utilizing the kinetic energy of expanding steam as it impinges on blades or buckets carried on the periphery of a wheel. There are two basic types: impulse and reaction. Each type employs a set of stationary nozzles or blades for each rotating wheel. In the impulse type, expansion occurs only as the steam is passing through the stationary blades. In the reaction type, expansion is continuous along the entire length of the machine, taking place also in the rotating blades. The impulse turbine may be built as a single-wheel machine known as the reentry type, in which the same steam, at successively lower pressures, is fed back to impinge on the same wheel at several different points. In its more common form, the impulse turbine consists of several wheels mounted on the same shaft, but separated by diaphragms. Each diaphragm carries nozzles for expanding the steam, which then gives up its kinetic energy to the adjacent wheel. Each wheel constitutes a "stage." Such a machine is essentially a series of single-wheel turbines, each of which receives steam at successively lower pressures.

In the reaction machine, stationary and rotating blades alternate for the entire length of the turbine. There are no separating diaphragms. This type is necessarily of considerable length in order to utilize the total available pressure drop of the steam. Expansion occurs in both the stationary and the rotating blades, so that the driving force is partly kinetic, partly the reaction of the steam as its volume increases in its passage through the moving blades.



Bleeder Turbo-Alternator of 1,500-Kw. Capacity, Supplying Process Steam at Bleeder and Exhaust Pressures

Such turbines are sometimes shortened by combining a high-pressure impulse section with a low-pressure reaction section mounted on the same shaft.

Although it is of no particular importance in industrial plants, the multi-cylinder or compound turbine should be mentioned. The capacity of power generation units is increased sometimes by the use of two- or three-cylinder machines which are essentially separate turbines, mounted either on the same shaft or on separate shafts, but arranged to use the same steam supply at successively lower pressures.

A somewhat more important classification of turbines is based on operation. Turbines intended primarily for power production generally exhaust to a condenser. Some condensing turbines, called bleeder or extraction turbines, may be built to bleed steam at one or more pressures, either to process or to closed feed-water heaters. Turbines intended to exhaust at pressures above atmospheric are often used as reducing valves for process-steam supply. They are known as back-pressure turbines. Other turbines have been developed to operate on low-pressure exhaust from engines and other prime-mover equipment. High-pressure turbines have been developed to exhaust through reheaters to lower-pressure turbines. Still one other important classification of turbines is the mixed-pressure machine. This is designed to operate on two separate steam supplies, a high-pressure supply and a low-pressure supply. Sometimes this machine regularly operates on low-pressure steam, utilizing high-pressure steam automatically when the low-pressure supply becomes inadequate. Or the reverse may be the case. Occasionally such turbines operate on both sorts of steam supply under all conditions.

Turbine Auxiliaries

Principal turbine auxiliaries include the governor, the condenser and the air pump. The governor maintains the turbine speed by regulating the steam supply. Condensers are of three types: surface condensers, jet and barometric condensers. Since the two latter types mix the cooling water with the condensate, they have serious limitations for use in large plants and the surface condenser is principally relied on. This consists of a shell-and-tube heat exchanger which reaches very large size in modern installations. Condensate is removed from the condenser by the use of a centrifugal condensate pump. Non-condensable gases are removed through the use of a steam-jet air pump or with some form of mechanically operated vacuum pump.

Cooling water supply is a difficult problem in many plants, as the quantity of water required may reach large proportions. Spray ponds and atmospheric and forced-draft cooling towers are frequently used to reduce the cooling water requirements. Centrifugal pumps are now used almost exclusively for cooling-water circulation.

Outside of the central station, the steam engine still retains considerable importance as a prime mover. It has the advantage of being a slow-speed machine, the speed of which is adjustable over a considerable range. It is thus adaptable to the driving of many forms of equipment which would require speed reduction if a turbine were to be used. The engine has the further advantages of low upkeep, high durability and smaller investment than is necessary for turbine equipment. In the uniflow type, which is the one principally used in large installations today, compound engines—that is, multi-cylinder engines using the same steam supply at successively lower pressures — are susceptible to the same bleeding and reheating possibilities as are turbines. For use in the regenerative cycle and for the supply of process steam, they can readily be designed to take care of most requirements.

❖

Correction: In an article entitled "A Graphical Method for Determining Pressure Drop and Heat Transfer in Pipes," by R. A. Bayard, appearing on pages 130-2 of our March, 1932, issue, mistakes occur on pages 131 and 132. In the formula for the "Air-Oil-Water Curve Factor" shown on the chart, substitute *plus* for *minus*. This is given correctly in the text. On page 132, in the example for determining the heat transfer coefficient, the conductivity, k, should be 0.08 instead of 0.8. This is given correctly on the chart.

NEWS *of the* INDUSTRY

Claim Chemists Unaffected By Depression

DESPITE the economic stress of depressing times, more than eight hundred chemists attended the New Orleans meeting of the American Chemical Society, March 28 to April 1, and learned from its officers that the organization had just completed one of the most satisfactory years in its history. Dr. L. V. Redman, as president, told the society that the secretary's canvass of its membership had revealed only 275 unemployed. Forty-three local sections had reported not a single unemployed member; twelve sections had reported only one unemployed; eight reported two; while eleven, including New York, Boston and Cleveland, had listed a total of 170. New members already added in 1932 total 1,172, but because of the greater number of resignations, there is actually a net loss of about 500 members.

Although no revolutionary advances in science or industry were reported at this meeting, a number of the papers received wide publicity in the public press. Notable among these was a report by Cox and Metschl, of Mellon Institute, that the addition of 6 per cent of cane sugar resulted in strengthening lime-sand mortar by as much as 60 per cent. Reviews of the cellulose industries by H. J. Skinner, of Boston, and of the development of tung-oil production in the South by H. A. Gardner, of Washington, also attracted popular attention.

Chemical engineering interest centered largely in a joint symposium of the industrial, petroleum and fuel divisions under the chairmanship of Robert T. Haslam, of New York City. In introducing the session on "Chemical Engineering Processes in the Petroleum Industry," the chairman stated that the efficiency of automotive power from crude oil had been increased 300 per cent in the last ten years. He attributed the change to increased engine efficiency, the production of anti-knock motor fuels and the increased yield of gasoline per barrel of crude oil. This has been realized by (1) larger use of cracking equipment, (2) improved operating practice to reduce losses due to waste in the forms of gas, coke and tar, and (3) improved fuel economy within the refinery. Gustav Egloff, of Chicago, remarked that more than half of the papers on the petroleum program related to distillation. Quoting extensively from the writings of Porta in 1553, he showed how even the ancients appreciated the basic importance of this unit operation.

❖

Gas Association Discusses Distribution Problems

DESIGNATING customer service as the keynote, the ninth annual convention of the American Gas Association distribution conference opened Wednesday, April 6, at the Tutwiler Hotel, Birmingham, Ala. Public utility gas engineers of the United States and Canada were present. Meetings were held through Friday, April 8.

Wednesday's meeting was opened by F. A. Lydecker, Newark, N. J. C. C. Simpson, Jr., New York City, reported for the committee on cast-iron-pipe standards. H. B. Anderson, Philadelphia Gas Co., followed, introducing a symposium on "Giving Good Service to Customers."

The afternoon program was opened with a report of the pipe joints committee by H. W. Battin, United Gas Improvement Co., Philadelphia. K. R. Knapp, A. G. A. Testing Laboratory, Cleveland, was next on the program with a paper on "Joint Pipe Research at A. G. A. Laboratory."

The second symposium carried the following discussions: "Welding Procedure for and Physical Characteristics of Arc Welded Pipe Joints," by O. A. Tilton, General Electric Co., Schenectady; "New Developments, Joint Characteristics and Procedure Specifications for Oxyacetylene Welding of Steel Pipe," by T. W. Greene, Linde Air Products Co., New York City; "Pipe Line Welding," by R. S. Fuller, Pacific Gas & Electric Co., San Francisco, and "Copper Pipe for Gas Distribution," by Arthur F. Bridge and Frederic A. Hough, Southern Counties Gas Co., Los Angeles.

Thursday was given over to an inspection trip to the various pipe manufacturing plants, arranged by local manufacturers. The inspection included plants where DeLavaud, pit-cast, McWane and monocast pipes are manufactured. A barbecue was served in North Birmingham Park.

F. A. Lydecker, Newark, N. J., was chairman of the conference; H. W. Hartman, New York City, secretary of the technical division; K. H. Cree, assistant secretary; and I. K. Peck, Midland United Co., chairman of the technical section.

A.I.Ch.E. Will Meet at Schenectady-Corning

PLANS for the summer meeting of the American Institute of Chemical Engineers call for meetings at Schenectady, June 15-16, and at Wellsboro, Pa., and Corning, N. Y., on June 17. Arrangements are in charge of a committee consisting of Dr. Willis R. Whitney, chairman; Dr. Eugene C. Sullivan, and Albert E. Marshall.

The Hotel VanCurler has been selected as headquarters at Schenectady. The two-day meeting there will include two technical sessions as well as a business session and inspection trips to various departments of the General Electric Co.'s plant. The customary banquet has been arranged for Wednesday evening. Thursday afternoon and evening will be devoted to a trip to the Helderburg Mountain Park, where an open air supper will be served.

Members will leave Schenectady around 11 p.m., June 16, on a special train which will arrive at Wellsboro, Pa., about 7.30 a.m., June 17. Breakfast will be served at Wellsboro and thereafter a visit will be paid to the factory of the Corning Glass Works. The special train will again be used to convey members from Wellsboro to Corning.

❖

Texas Seeks to Uncover Sal Ammoniac Deposit

CRYSTALS of practically pure sal ammoniac separating from a slush pond alongside an abandoned oil well near Gail, Borden County, Texas, have led a small group of Fort Worth oil producers, headed by R. H. Dulaney and including D. A. Moncrief and Harry G. Wuinnup, to drill another well in hopes of locating a commercial deposit. This whole territory is underlain with heavy deposits of water-soluble salts, such as sylvite, now being mined for potash. Chemists and geologists in that vicinity who were interviewed by a representative of *Chem. & Met.* were frankly skeptical of any appreciable occurrence of ammonium chloride but were keenly interested in the analysis being made in the field by a qualified representative of Fort Worth consulting chemists.

The new well was down to 1,200 ft. last week and it was expected that a salt bed would shortly be entered. The original oil well was abandoned at 3,600 ft.

NEWS FROM WASHINGTON

By Paul Wooton

Washington Correspondent of Chem. & Met.

SULPHUR PRODUCERS are granted a fixed depletion allowance of 27½ per cent of gross income by the tax bill as it passed the House. The provision placing sulphur in the same category as oil and gas wells was proposed by Representative Mansfield, of Texas, with the explanation that sulphur producers have invariably obtained a greater allowance for depletion in the past but have been put to great expense in presenting their claims to the Bureau of Internal Revenue. No change has been made in the basis for allowing depletion in mineral mines. Many operators have actively sought to obtain allowances based on 33⅓ per cent of net income before depletion, where such allowances would not be less than if computed on the basis of cost or of value as of March 1, 1913. Representative Crisp, acting chairman of the Ways and Means Committee, announced, however, that because of the conflict of views in the mining industry, the committee decided against making any change in the basis for figuring depletion allowances. He suggested that further hearings may be held on this matter for the purpose of framing legislation to be considered independently of the general revenue bill.

Opposition to the Bingham volatile poison bill was voiced at a hearing before the Senate Committee on Agriculture by Warren Watson, secretary of the Manufacturing Chemists' Association, and other representatives of the industry. The committee was told that there is no occasion for legislation that would detract from the precautionary effect of poison labels by multiplying their use. Labeling of numerous products included in the bill now is required by state law, several others do not enter the household, and with respect to the remainder there is no evidence, said Mr. Watson, that they are harmful. A definite suggestion was made that the manufacturers would cooperate with the Surgeon General in labeling products entering the household that are found to be hazardous to health or life.

INSECTICIDE manufacturers decided, after reviewing laboratory tests at a recent meeting in New York City, to undertake semi-commercial production of colored insecticides for use in field tests this summer. This investigation was prompted by the introduction in Congress and in state legislatures of numerous bills that would require discoloration of poisons which resemble commonly used foodstuffs. The meeting of the insecticide manufacturers April 8 marked the organization of a committee that will take over the functions of the American Insecticide and Fungicide Manufacturers' Association. A series of handbooks on procedure for the handling of chemical containers in the plants of both manufacturers and consumers was approved at a meeting of the manual committee April 11.

DOMESTIC producers were granted a hearing on charges that European sulphate of ammonia is being dumped in this country, but it is not expected that the Bureau of Customs will regard the evidence as sufficiently conclusive to warrant an anti-dumping order. The low price of ammonium sulphate in Europe has led, according to reports here, to renewal of the attempt to organize a cartel. Large sales combined with curtailed output have depleted stocks, estimated, in some quarters, as sufficient only to last until the end of April. Because of the protection thrown about its market, France is not likely to enter any agreement aiming at stabilizing prices at a higher level.

The Tariff Commission's report finding that no duty on creosote oil is necessary to equalize domestic and British costs has raised the question whether the Commission's findings are not susceptible to political bias. The Commission's cost figures are criticized as failing to give sufficient weight to tar as an element of cost, but beyond that there is the claim that in finally adopting a comparison showing the British cost as 13.47c. per gallon, including transportation, and the domestic cost as 13.01c., the Commission ignored other comparisons that would have given more than sufficient warrant for tariff protection. The Commission's report to the Senate was confined, as directed, to data covering the years 1928, 1929 and 1930. In view of this limitation, the Commission did not undertake to ascertain the effect of the depreciation of the pound sterling since England went off the gold standard last September. The report notes, however, that since depreciation set in imports from the United Kingdom through January fell off, totaling 5,098,000 gal., as compared with 6,529,000 gal. in the corresponding period a year previous.

The Tariff Commission has announced an investigation on high-test lithopone on application of Sachtleben Mining & Chemical Corp., of Cologne, Germany, looking toward a decrease in the present duty of 1¼c. per pound and 15 per cent ad valorem. The investigation order specifies lithopone containing 30 per cent zinc sulphide.

THE question whether an imported dye mixture is dutiable on its invoice price or on the basis of the American selling price of two domestic dyes that when combined produce substantially the same result has been remanded by the U. S. Court of Customs Appeals for reconsideration by the U. S. Customs Court. The lower court had previously held that Discharge Blue B G extra, a mixture imported by the General Dyestuffs Corp., was dutiable at its import price because no similar competitive dye was available on the domestic market. The government contended that the imported dye should pay duty on the basis of the selling price of two domestic dyes, Fast Acid Green B and Fast Wool Violet 2 R, mixed in proportions of 8 and 92 per cent, respectively. The appellate court held that the lower court should not have ruled out the government's evidence to the effect that it was not the custom of dyemakers to stock mixtures when they have the constituent parts on hand but are in a position to make delivery of the mixture within 12 hours. Paragraph 28 of the 1930 tariff should not be so narrowly and technically construed as to take from it the effect which Congress intended, said the appellate court in remanding the case.

Soviet Russia has hinted that if negotiations for the exchange of petroleum for Chile nitrate do not go through, the Soviet will expand its own plant. The government has offered to take as a starter 50,000 tons of nitrate in exchange for gasoline, lubricating and fuel oil having an equivalent value of $1,250,000, if the price of the nitrate is estimated at $25 per ton f.o.b. Chile. Unable to undertake distribution of the petroleum products, Cosach has suggested that the Chilean government accept them in lieu of its large periodic cash payments. The proposal may fit into the scheme for establishing a government oil monopoly which also is under consideration.

The proposal of manufacturers to insure greater safety in distribution of insecticides by coloring these products emphasizes the regard for health-protection which producers of poisonous products exercise in placing their goods in the hands of consumers. In the March issue of *Chem. & Met.* editorial reference was made to a report that it was common in the South to parcel out calcium arsenate from a container under the general-store counter. In view of existing federal and state laws regulating the sale of poisons, it is highly improbable that it would be common, even for small distributors, to make sales except in the original unopened containers.—EDITOR.

MEN
IN CHEMICAL ENGINEERING

A. L. LOEBENBERG has been appointed vice-president of the U. S. Industrial Chemical Co., Inc., a subsidiary of the U. S. Industrial Alcohol Co. Mr. Loebenberg comes from executive positions in the American Machine & Metals, Inc., after being director of manufacture for the National Aniline & Chemical Co. and Becker's Aniline Chemical Works, Inc.

J. E. LOCKWOOD, for the past 12 years in the naval stores department of Hercules Powder Co., has resigned to become a consulting engineer, with offices at Savannah, Ga. He will continue to act as consultant to the Hercules Powder Co. Mr. Lockwood has been active in the naval stores industry for 24 years and took part in the commercial development of many technical innovations.

HECTOR R. CARVETH, president of the Roessler & Hasslacher Chemical Co., has resigned as president and member of the board. At the same time he resigned as director of the parent company, E. I. du Pont de Nemours & Co. Dr. Carveth, who is retiring to private life, has been with this company for over 25 years, before which he was connected with the Acheson Graphite Co. and Niagara Electro-Chemical Co., after teaching for eight years at Cornell.

CHARLES K. DAVIS, president of the Du Pont Viscoloid Co., a subsidiary of the du Pont company, has been elected president of the Roessler & Hasslacher Chemical Co., another subsidiary, to succeed H. R. Carveth, who has resigned.

F. B. LANGRECK, works manager of the Monsanto Chemical Works plant at Monsanto, Ill., has been made assistant vice-president.

EDWARD J. JONES has left the Victor Chemical Works, Chicago, to become director of research of the Champaign Paper Corp. of France and the United States, in New York City.

RAYMOND B. LADOO, formerly with the U. S. Gypsum Co., Chicago, has resigned to open a consultant's office at Belmont, Mass., for sales and consulting work on non-metallic minerals.

CHARLES L. PARSONS, for 25 years secretary of the American Chemical Society and formerly professor of chemistry at the University of New Hampshire, was recipient of the Priestley Medal for distinguished service to chemistry at the society's recent meeting in New Orleans. The last recipient had been F. P. Garvan.

A. D. CAMP, for the last three years engaged in the development of chemical applications for carbon at the National Carbon Co., has become director of research and development of the Ideal Roller & Manufacturing Co. at its Chicago plant.

JAMES A. LEE, for the past three years assistant editor of *Chem. & Met.*, has been promoted to managing editor. Mr. Lee joined the staff of the paper at the

end of 1928 after an eight years' connection with the Bell Telephone Laboratories, New York City, and prior service in the Chemical Warfare Service and Citizens Gas Co., Indianapolis.

JAMES W. HARRIS, mill manager of the Oxford Paper Co., Rumford, Maine, has resigned after almost 25 years of service with this company.

ARNOLD E. PITCHER, who was vice-president of the Du Pont Viscoloid Co., has been promoted to president to succeed Charles K. Davis, who became president of the Roessler & Hasslacher Chemical Co. Mr. Pitcher has been with the parent company since 1910, when he joined the pyralin department at Arlington, N. J. After it was merged with the Du Pont Viscoloid Co. he became executive vice-president.

❖

OBITUARY

DAVID L. JACOBSON, chemical engineer for the Koppers Research Corp., died on March 6 at his home in Pittsburgh after an attack of pneumonia. He had been with the company since 1917 and was a recognized authority on the purification of gas. Born in Jersey City in 1892, he was educated at Columbia University and Massachusetts Institute of Technology and then entered professional work as chemical engineer with the Corn Products Refining Co. and Tidal Gasoline Co. His first connection with the Koppers company began on the research staff at the Seaboard plant, Kearny, N. J.

GEORGE V. EBNER, long identified with the chemical aspects of ink manufacture, died in New York of pneumonia at the age of 74. Dr. Ebner came to this country from Germany, after receiving his education, when he was 23 years old. He was first engaged in drug research, but soon devoted his attention to writing and printing inks, for which he conducted successful research for practically the rest of his life.

WILHELM OSTWALD, one of the greatest figures participating in the progress of chemistry before the war, died at his home near Leipzig, Germany, on April 4, in his 79th year. Prof. Ostwald was born in Riga, educated at Dorpat University, but soon after beginning a career of teaching was called to the chair of physical chemistry at Leipzig. It was here that he engaged his productive efforts thereafter, culminating in the Nobel prize for chemistry in 1909 and the foundation of the *Zeitschrift für Physikalische Chemie*. It was he who succeeded in combining the descriptive and physical phases of chemistry into a fundamental system now generally recognized; he showed that all chemical changes are subject to general thermodynamic laws. Since the War he devoted his energies to various other fields, such as the forms and economics of community life, and the theory of colors, in which he established new fundamental concepts.

CALENDAR OF COMING EVENTS

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS, spring meeting, Schenectady and Corning, N. Y., June 15-17.

AMERICAN INSTITUTE OF CHEMISTS, annual meeting, New York, May 7.

AMERICAN GAS ASSOCIATION, Atlantic City, June 3-4.

AMERICAN SOCIETY FOR TESTING MATERIALS, annual meeting, Atlantic City, N. J., June 20-24.

COLLOID SYMPOSIUM, American Chemical Society, Ottawa, Canada, June 16-18.

ELECTROCHEMICAL SOCIETY, spring meeting, Baltimore, April 21-23.

ECONOMIC INFLUENCES

on production and consumption of CHEMICALS

Moderate Gain in Distribution of Chemical Products

Large Consuming Industries Show Varying Rate of Activities

WHILE improvement was reported in the distribution of chemicals last month, spotted conditions in some of the large consuming industries prevented gains up to the full seasonal standard. For instance, calls for alkali deliveries were more active in some quarters but curtailed production of rayon restricted the movement to that industry. Oil refiners likewise appear to have cut down consumption of chemicals to a greater degree than refining operations would indicate. Fertilizer chemicals improved their position but little and tag sales for March were only 48 per cent of the sales for March, 1931. Good demand for raw materials has come from the soap and paint trades, with the textile industry also taking on stocks in satisfactory volume.

The outlook for consumption of chemicals in the second quarter of this year in the eastern part of the country is indicated in reports read at the meeting of the Atlantic States Shippers' Advisory Board held on March 24. Car requirements for the movement of chemicals and explosives during the quarter were estimated at 7,230, compared with 7,227 cars actually shipped in the corresponding quarter of 1931.

Estimates of car requirements for some of the process industries were less favorable than were those for chemicals. Among these reports were declines of 6 per cent for hides, leather, and tanning materials; 10.4 per cent for paints and varnishes; 13.8 per cent for salt; 25 per cent for fertilizers; and 12 per cent for glass containers.

Price fluctuations have resulted largely from developments relating to the affected product and not to any general trend. Consuming demand has not broadened to an extent where a firm undertone is noted; in fact, concessions from quoted levels continue throughout the greater part of the market. This does not mean that the market as a whole developed price weakness in the last month but rather that conditions have not improved sufficiently to warrant the belief that an upturn in values is imminent. Higher prices for acetic acid followed the rise in acetate of lime and hence represents increased production cost, although producers of synthetic acetic acid aided in the movement by joining in the advance. Borax was lowered sharply in price, but this was adjusting the open price, to levels which had been the basis of trading for some time. Production of borax has increased and competitive influences influenced the price change.

Tin salts were reduced materially, and this again was the effect of lower production costs. Carbon gas black also was lowered one-quarter cent per pound.

PROMINENT among tariff developments was the report submitted by the Tariff Commission giving the results of an investigation of the differences in cost of production of dead or creosote oil in the United States and in the principal competing country. The investigation found that for the three-year period 1928-1930, cost of production of domestic creosote oil, including transportation and other delivery charges to the principal markets in this country, was 13.01c. per gallon and the corresponding cost of the product from the United Kingdom—the principal competing country—was 13.47c. per gallon. In view of these relative prices the commission found no sufficient warrant on the basis of cost differences for a duty on creosote oil.

EXPORT trade in chemicals and related products in February carried a valuation of $6,450,648 compared with $8,100,622 for February, 1931. In the coal-tar group marked declines were reported for benzol, colors, and dyes. Smaller export shipments were almost general in the industrial chemical group, although methanol, acetone, nitro or aceto cellulose solutions, and calcium carbide offered exceptions.

The outward movement of sodium compounds totaled 30,840,952 lb. as against 36,513,591 lb. for February of last year. Bichromate, silicate, and phosphates were the only sodium products to surpass the totals for last year, but the decline in borax shipments was small, with the total for the month holding above 12,000,000 lb., and for the two-month period, January-February, they show a difference of more than 6,000,000 lb. in favor of the present year. Among fertilizer materials the loss of foreign trade in sulphate of ammonia is prominent, the two-months' figures for this year being 9,962 tons, compared with 24,542 for last year.

Import trade in chemicals and related products in February was valued at $4,455,675, compared with $7,562,371 for February, 1931. Creosote oil, coal-tar dyes, arsenic, oxalic acid, ammonium chloride, ammonium nitrate, cobalt oxide, and sodium cyanide were among the materials which registered gains over last year. Sulphate of ammonia also reached this country in larger volume; receipts for the first two months of the year were 38,419 tons, compared with 18,662 tons for the comparable period of 1931.

Chem. & Met. Weighted Index of Chemical Prices

Base = 100 for 1927

This month	**85.01**
Last month	85.29
April, 1931	87.86
April, 1930	97.36

While spirits of turpentine and all grades of acetic acid held a higher average level during the month, borax, boric acid, and citric acid sold at lower prices and the weighted index number settled at a fractional decline.

Chem. & Met. Weighted Index of Prices for Oils and Fats

Base = 100 for 1927

This month	**41.55**
Last month	46.34
April, 1931	72.27
April, 1930	94.46

The lowest price level in recent years was reached last month in the market for oils and fats. Price declines were general and, in addition to declines in vegetable oils, lower prices ruled for animal fats and glycerine.

CURRENT PRICES *in the* NEW YORK MARKET

THE following prices refer to round lots in the New York market. Where it is the trade custom to sell f.o.b. works, quotations are given on that basis and are so designated. Prices are corrected to April 13.

Industrial Chemicals

	Current Price	Last Month	Last Year
Acetone, drums, lb.	$0.10 -$0.11	$0.10 -$0.11	$0.10.-$0.11
Acid, acetic, 28%, bbl., cwt.	2.65 - 2.90	2.65 - 2.90	2.60 - 2.85
Glacial 99%, tanks	8.89	8.89 -	8.98 -
drs	9.14 - 9.39	9.14 - 9.39	9.23 - 9.48
U. S. P. reagent, c'bys.	9.64 - 9.89	9.64 - 9.89	9.73 - 9.98
Boric, bbl., lb.	.04½- .05	.06½- .07	.06½- .07
Citric, kegs, lb.	.32 - .32½	.33½- .35	.40 - .41
Formic, bbl., lb.	.10 - .11	.10 - .11	.10 - .11
Gallic, tech., bbl., lb.	.50 - .55	.50 - .55	.50 - .55
Hydrofluoric 30% carb., lb.	.06 - .07	.06 - .07	.06 - .07
Lactic, 44%, tech., light, bbl., lb.	.11½- .12	.11½- .12	.11½- .12
22%, tech., light, bbl., lb.	.05½- .06	.05½- .06	.05½- .06
Muriatic, 18° tanks, cwt.	1.00 - 1.10	1.00 - 1.10	1.00 - 1.10
Nitric, 36°, carboys, lb.	.05 - .05½	.05 - .05½	.05 - .05½
Oleum, tanks, wks., ton	18.50 -20.00	18.50 -	18.50 -20.00
Oxalic, crystals, bbl., lb.	.11 - .11½	.11 - .11½	.11 - .12
Phosphoric, tech., c'bys., lb.	.08½- .09	.08½- .09	.08½- .09
Sulphuric, 60°, tanks, ton	11.00 -11.50	11.00 -11.50	11.00 -11.50
Sulphuric, 66°, tanks, ton	15.50 -	15.50 -	15.50 -
Tannic, tech., bbl., lb.	.23 - .35	.23 - .35	.23 - .35
Tartaric, powd., bbl., lb.	.24½- .25	.24½- .25	.30½- .33
Tungstic, bbl., lb.	1.40 - 1.50	1.40 - 1.50	1.40 - 1.50
Alcohol, ethyl, 190 p'f., bbl., gal.	2.53½-	2.53½-	2.33 -
Alcohol, Butyl, tanks, lb.	.113 -	.143 -	.15½-
Alcohol, Amyl	-	-	-
From Pentane, tanks, lb.	.203-	.203-	.236-
Denatured, 188 proof			
No. 1 special dr., gal.	.34½-	.34½-	.27 -
No. 5, 188 proof, dr., gal.	.35½-	.35½-	.27 -
Alum, ammonia, lump, bbl., lb.	.03 - .04	.03½- .04	.03½- .04
Chrome, bbl., lb.	.04½- .05	.04½- .05	.04½- .05
Potash, lump, bbl., lb.	.03 - .04	.03½- .04	.03½- .04
Aluminum sulphate, com., bags, cwt.	1.25 - 1.40	1.25 - 1.40	1.25 - 1.40
Iron free, bg., cwt.	1.90 - 2.00	1.90 - 2.00	1.90 - 2.00
Aqua ammonia, 26°, drums lb.	.02½- .03	.02½- .03	.02½- .03
tanks, lb.	.02½- .02½	.02½- .02½	.02½- .02½
Ammonia, anhydrous, cyl., lb.	.15½- .15½	.15½- .15½	.15½- .15½
tanks, lb.	.05½-	.05½-	.05½-
Ammonium carbonate, powd. tech., casks, lb.	.10½- .11	.10½- .11	.10½- .11
Sulphate, wks., cwt.	1.00 -	1.00 -	1.75 -
Amylacetate tech., tanks, lb., gal.	.16 -	.16 -	.222-
Antimony Oxide, bbl., lb.	.06½- .08	.06½- .08	.08½- .10
Arsenic, white, powd., bbl., lb.	.04 - .04½	.04 - .04½	.04 - .04½
Red, powd., kegs, lb.	.09 - .10	.09 - .10	.09 - .10
Barium carbonate, bbl., ton.	56.50 -58.00	56.50 -58.00	58.00 -60.00
Chloride, bbl., ton	63.00 -65.00	63.00 -65.00	63.00 -65.00
Nitrate, cask, lb.	.07 - .07½	.07 - .07½	.07 - .07½
Blanc fixe, dry, bbl., lb.	.03½- .04	.03½- .04	.03½- .04
Bleaching powder, f.o.b., wks., drums, cwt.	1.75 - 2.00	1.75 - 2.00	2.00 - 2.10
Borax, grain, bags, ton	40.00 -45.00	50.00 -57.00	50.00 -57.00
Bromine, cs., lb.	.36 - .38	.36 - .38	.36 - .38
Calcium acetate, bags	2.50 -	2.50 -	2.00 -
Arsenate, dr., lb.	.05½- .06½	.05½- .06½	.07 - .08
Carbide drums, lb.	.05 - .06	.05 - .06	.05 - .06
Chloride, fused, dr., wks., ton.	18.00 -	18.00 -	20.00 -
flake, dr., wks., ton.	21.00 -	21.00 -	22.75 -
Phosphate, bbl., lb	.08 - .08½	.08 - .08½	.08 - .08½
Carbon bisulphide, drums, lb.	.05 - .06	.05 - .06	.05 - .06
Tetrachloride drums, lb.	.06½- .07	.06½- .07	.06½- .07
Chlorine, liquid, tanks, wks., lb.	.01½-	.01½-	.01½-
Cylinders	.04 - .06	.04 - .06	.04 - .06
Cobalt oxide, cans, lb.	1.25 - 1.35	1.35 - 1.45	1.75 - 1.85
Copperas, bgs., f.o.b. wks., ton.	13.00 -14.00	13.00 -14.00	13.00 -14.00
Copper carbonate, bbl., lb.	.07 - .16	.07 - .16	.08½- .18
Cyanide, tech., bbl., lb.	.39 - .44	.39 - .44	.41 - .46
Sulphate, bbl., cwt.	2.75 - 2.90	2.75 - 2.90	4.25 - 4.50
Cream of tartar, bbl., lb.	.19½- .19½	.19½- .19½	.23½- .24
Diethylene glycol, dr., lb.	.14 - .16	.14 - .16	.14 - .16
Epsom salt, dom., tech., bbl., cwt.	1.70 - 2.00	1.70 - 2.00	1.70 - 2.00
Imp., tech., bags, cwt.	1.15 - 1.25	1.15 - 1.25	1.15 - 1.25
Ethyl acetate, drums, lb.	.10 -	.10 -	.085-
Formaldehyde, 40%, bbl., lb.	.06 - .07	.06 - .07	.06 - .07
Furfural, dr., contract, lb.	.10 - .17½	.10 - .17½	.10 - .17½
Fusel oil, crude, drums, gal.	1.10 - 1.20	1.10 - 1.20	1.30 - 1.40
Refined, dr., gal.	1.80 - 1.90	1.80 - 1.90	1.90 - 2.00
Glaubers salt, bags, cwt.	1.00 - 1.10	1.00 - 1.10	1.10 - 1.20
Glycerine, c.p., drums, extra, lb.	.10½- .11	.11½- .11½	.12½- .13
Lead:			
White, basic carbonate, dry casks, lb.	.06½-	.06½-	.07½-
White, basic sulphate, sck., lb.	.06 -	.06 -	.07 -
Red, dry, sck., lb.	.06½-	.06½-	.08 -
Lead acetate, white crys., bbl., lb.	.10 - .11	.10½- .11	.11 - .12
Lead arsenate, powd., bbl., lb.	.10 - .14	.10 - .14	.13 - .14
Lime, chem., bulk, ton	8.50 -	8.50 -	8.50 -
Litharge, pwd., csk, lb.	.05½-	.05½-	.07 -
Lithophone, bags, lb.	.04½- .05	.04½- .05	.04½ .05
Magnesium carb., tech., bags, lb.	.05½- .06	.05½- .06	.06 - .06½
Methanol, 95%, tanks, gal.	.33 -	.33 -	.33 -
97%, tanks, gal.	.34 -	.34 -	.34 -
Synthetic, tanks, gal.	.35½-	.35½-	.40½-
Nickel salt, double, bbl., lb.	.10½- .11	.10½- .11	.10½- .11
Single, bbl., lb.	.10½- .11	.10½- .11	.10½- .11
Orange mineral, csk., lb.	.09½-	.09½-	.10 -
Phosphorus, red, cases, lb.	.42 - .44	.42 - .44	.42 - .44
Yellow, cases, lb.	.31 - .32	.31 - .32	.31 - .32
Potassium bichromate, casks, lb.	.08 - .08½	.08 - .08½	.09 - .09½
Carbonate, 80-85%, calc., csk., lb	.05 - .05½	.05 - .05½	.05½- .06
Chlorate, powd., lb.	.08 - .08½	.08 - .08½	.08 - .08½
Cyanide, cs., lb.	.50 - .55	.55 - .57	.55 - .57
Hydroxide (c'stic potash) dr., lb.	.06½- .06½	.06½- .06½	.06½- .06½
Muriate, 80% bgs., ton	37.15 -	37.15 -	37.15 -
Nitrate, bbl., lb.	.05½- .06	.05½- .06	.05½- .06
Permanganate, drums, lb.	.16 - .16½	.16 - .16½	.16 - .16½
Prussiate, yellow, casks, lb.	.18½- .19½	.18½- .19	.18½- .19
Sal ammoniac, white, casks, lb.	.04½- .05	.04½- .05	.04½- .05
Salsoda, bbl., cwt.	.90 - .95	.90 - .95	.90 - .95
Salt cake, bulk, ton	16.00 -18.00	16.00 -18.00	15.00 -18.00
Soda ash, light, 58%, bags, contract, cwt.	1.15 -	1.15 -	1.15 -
Dense, bags, cwt.	1.17½-	1.17½-	1.17½-
Soda, caustic, 76%, solid, drums, contract, cwt.	2.50 - 2.75	2.50 - 2.75	2.50 - 2.75
Acetate, works, bbl., lb.	.05 - .06	.05 - .06	.04½- .05
Bicarbonate, bbl., cwt.	1.85 - 2.00	1.85 - 2.00	1.85 - 2.00
Bichromate, casks, lb.	.05 - .06	.05 - .06	.07 - .07½
Bisulphate, bulk, ton	14.00 -16.00	14.00 -16.00	14.00 -16.00
Bisulphite, bbl., lb.	.03½- .04	.03½- .04	.03½- .04
Chlorate, kegs, lb.	.05½- .07½	.05½- .07½	.05½- .07½
Chloride, tech., ton	12.00 -14.75	12.00 -14.75	12.00 -14.00
Cyanide, cases, dom., lb.	.15½- .16	.15½- .16	.16½- .17
Fluoride, bbl., lb.	.07½- .08	.07½- .08	.08 - .09
Hyposulphite, bbl., lb.	2.40 - 2.50	2.40 - 2.50	2.40 - 2.50
Nitrate, bags, cwt.	1.77 -	1.77 -	2.05 -
Nitrite, casks, lb.	.07½- .08	.07½- .08	.07½- .08
Phosphate, dibasic, bbl., lb.	2.55 - 2.75	2.55 - 2.75	.0265 - .03
Prussiate, yel. drums, lb.	.11½- .12	.11½- .12	.11½- .12
Silicate (30°, drums), cwt.	.60 - .70	.60 - .70	.60 - .70
Sulphide, fused, 60-62%, dr., lb.	.02½- .03½	.02½- .03	.02½- .03
Sulphite, cyrs., bbl., lb.	.03 - .03½	.03 - .03½	.03 - .03½
Sulphur, crude at mine, bulk, ton	18.00 -	18.00 -	18.00 -
Chloride, dr., lb.	.03½- .04	.03½- .04	.05 - .06
Dioxide, cyl., lb.	.06½- .07	.06½- .07	.06½- .07
Flour, bag, cwt.	1.55 - 3.00	1.55 - 3.00	1.55 - 3.00
Tin bichloride, bbl., lb.	nom.-	nom.-	nom.-
Oxide, bbl., lb.	.24½-	.25½-	.28 -
Crystals, bbl., lb.	.22 -	.23½-	.25½-
Zinc chloride, gran., bbl., lb.	.06 - .06½	.06½- .06½	.06½- .06½
Carbonate, bbl., lb.	.10½- .11	.10½- .11	.10½- .11
Cyanide, dr., lb.	.38 - .42	.41 - .42	.41 - .42
Dust, bbl., lb.	.04½- .05	.05½- .06	.06 - .07
Zinc oxide, lead free, bag, lb.	.05½-	.05½-	.06½-
5% lead sulphate, bags, lb.	.05½-	.05½-	.06½-
Sulphate, bbl., cwt.	3.00 - 3.25	3.00 - 3.25	3.00 - 3.25

Oils and Fats

	Current Price	Last Month	Last Year
Castor oil, No. 3, bbl., lb.	$0.09½-$0.10½	$0.09½-$0.10	$0.10½-$0.11
Chinawood oil, bbl., lb.	.06 -	.07½-	.07 -
Coconut oil, Ceylon, tanks, N. Y. lb.	.03½-	.03½-	.05 -
Corn oil crude, tanks, (f.o.b. mill), lb.	.03½-	.03½-	.07½-
Cottonseed oil, crude (f.o.b. mill), tanks, lb.	.02½-	.03½-	.06½-
Linseed oil, raw car lots, bbl., lb.	.064-	.067-	.09 -
Palm, Lagos, casks, lb.	.03½-	.03½-	.06½-
Niger, casks, lb.	.03½-	.03½-	.05½-
Palm Kernel, bbl., lb.	.04½-	.05½-	.05½-
Peanut oil, crude, tanks (mill), lb.	.03½-	.03½-	.07 -
Rapeseed oil, refined, bbl., gal.	.37 - .38	.39 - .41	.54 - .56
Soya bean, tank (f.o.b. Coast), lb	nom.-	nom.-	nom.-
Sulphur (olive foots), bbl., lb.	.04½-	.05 -	.05½-
Cod, Newfoundland, bbl., gal.	.25 - .27	.25 - .27	.42 - .45
Menhaden, light pressed, bbl., gal.	.33 - .34	.33 - .34	.34 - .36
Crude, tanks (f.o.b. factory), gal.	nom.-	.20 -	.20 -
Whale, crude, tanks, gal.	nom.-	nom.-	- nom.
Grease, yellow, loose, lb.	.02 -	.02 -	.03 -
Oleo stearine, lb.	.04½-	.04½-	.08½-
Red oil, distilled, d.p. bbl., lb.	.06½-	.06½-	.08½-
Tallow, extra, loose, lb.	.02½-	.02½-	.03½-

Coal-Tar Products

	Current Price	Last Month	Last Year
Alpha-naphthol, crude, bbl., lb.	$0.60 -$0.65	$0.60 -$0.65	$0.60 -$0.62
Refined, bbl., lb.	.80 - .85	.80 - .85	.80 - .85
Alpha-naphthylamine, bbl., lb.	.32 - .34	.32 - .34	.32 - .34
Aniline oil, drums, extra, lb.	.14½- .15	.14½- .15	.15 - .16
Aniline salts, bbl., lb.	.24 - .25	.24 - .25	.24 - .52

Coal-Tar Products (Continued)

	Current Price	Last Month	Last Year
Benzaldehyde, U.S.P., dr., lb.	$1.10 –$1.25	$1.10 –$1.25	$1.10 –$1.25
Benzidine base, bbl., lb.	.65 – .67	.65 – .67	.65 – .67
Benzoic acid, U.S.P., kgs, lb.	.48 – .52	.48 – .52	.57 – .60
Benzyl chloride, tech., dr., lb.	.30 – .35	.30 – .35	.30 – .35
Benzol, 90%, tanks, works, gal.	.20 – .21	.20 – .21	.20 – .21
Beta-naphthol, tech., drums, lb.	.22 – .24	.22 – .24	.22 – .24
Cresol, U. S. P., dr., lb.	.10½– .11	.10½– .11	.14 – .17
Cresylic acid, 97%, dr., wks., gal.	.49 – .52	.49 – .52	.54 – .58
Diethylaniline, dr., lb.	.55 – .58	.55 – .58	.55 – .58
Dinitrophenol, bbl., lb.	.29 – .30	.29 – .30	.29 – .30
Dinitrotoluen, bbl. lb.	.16 – .17	.16 – .17	.16 – .17
Dip oil 25% dr., gal.	.23 – .25	.23 – .25	.26 – .28
Diphenylamine, bbl., lb.	.38 – .40	.38 – .40	.38 – .40
H-acid, bbl., lb.	.65 – .70	.65 – .70	.65 – .70
Naphthalene, flake, bbl., lb.	.03½– .04¼	.03½– .04¼	.03½– .04¼
Nitrobenzene, dr., lb.	.08½– .09	.08½– .09	.08½– .10
Para-nitraniline, bbl., lb.	.51 – .55	.51 – .55	.51 – .55
Para-nitrotoluine, bbl., lb.	.26 – .28	.26 – .28	.29 – .31
Phenol, U.S.P., drums, lb.	.14½– .15	.14½– .15	.14½– .15
Picric acid, bbl., lb.	.30 – .40	.30 – .40	.30 – .40
Pyridine, dr., lb.	1.50 – 1.75	1.50 – 1.80	1.50 – 1.80
R-salt, bbl., lb.	.40 – .44	.40 – .44	.40 – .44
Resorcinal, tech., kegs, lb.	.65 – .70	.65 – .70	1.15 – 1.25
Salicylic acid, tech., bbl., lb.	.33 – .35	.33 – .35	.33 – .35
Solvent naphtha, w.w., tanks, gal.	.26 –.....	.26 –.....	.25 – .30
Tolidine, bbl., lb.	.86 – .88	.86 – .88	.86 – .88
Toluene, tanks, works, gal.	.30 –.....	.30 –.....	.30 –.....
Xylene, com., tanks, gal.	.26 –.....	.26 –.....	.25 – .28

Miscellaneous

	Current Price	Last Month	Last Year
Barytes, grd., white, bbl., ton.	$22.00–$25.00	$22.00–$25.00	$23.00–$25.00
Casein, tech., bbl., lb.	.06 – .10½	.07 – .14	.07½– .11
China clay, dom., f.o.b. mine, ton	8.00 –20.00	8.00 –20.00	8.00 –20.00
Dry colors:			
Carbon gas, black (wks.), lb.	.03 – .20	.03 – .20	.03½– .20
Prussian blue, bbl., lb.	.35 – .36	.35 – .36	.35 – .36
Ultramine blue, bbl., lb.	.06 – .32	.06 – .32	.06 – .32
Chrome green, bbl., lb.	.27 – .28	.27 – .28	.27 – .30
Carmine red, tins, lb.	5.25 – 5.40	5.25 – 5.40	5.00 – 5.40
Para toner, lb.	.75 – .80	.75 – .80	.77 – .80
Vermilion, English, bbl., lb.	1.45 – 1.50	1.45 – 1.50	1.70 – 1.80
Chrome yellow, C. P., bbl., lb.	.16 – .16½	.16 – .16½	.16½– .17
Feldspar, No. 1 (f.o.b. N.C.), ton	6.50 – 7.50	6.50 – 7.50	6.50 – 7.50
Graphite, Ceylon, lump, bbl., lb.	.07 – .08½	.07 – .08½	.07 – .08½
Gum copal Congo, bags, lb.	.06 – .08	.06 – .08	.07 – .09
Manila, bags, lb.	.16 – .17	.16 – .17	.16 – .17
Damar, Batavia, cases, lb.	.16 – .16½	.16 – .19	.16 – .16½
Kauri No. 1 cases, lb.	.45 – .48	.45 – .48	.48 – .53
Kieselguhr (f.o.b. N.Y.), ton.	50.00 –55.00	50.00 –55.00	50.00 –55.00
Magnesite, calc, ton.	40.00 –.....	40.00 –.....	40.00 –.....
Pumice stone, lump, bbl., lb.	.05 – .07	.05 – .08	.05 – .07
Imported, casks, lb.	.03 – .40	.03 – .40	.03 – .35
Rosin, H., bbl.	4.10 –.....	4.30 –.....	6.35 –.....
Turpentine, gal.	.44½–.....	.44½–.....	.54½–.....
Shellac, orange, fine, bags, lb.	.26 – .28	.32 – .34	.41 – .42
Bleached, bonedry, bags, lb.	.20 – .21	.24 – .26	.28 – .40
T. N. bags, lb.	.12 – .13	.12 – .13	.17 – .18
Soapstone (f.o.b. Vt.), bags, ton	10.00 –12.00	10.00 –12.00	10.00 –12.00
Talc, 200 mesh (f.o.b. Vt.), ton.	8.00 – 8.50	8.00 – 8.50	9.50 –.....
300 mesh (f.o.b. Ga.), ton.	7.50 –10.00	7.50 –10.00	7.50 –11.00
225 mesh (f.o.b. N. Y.), ton.	13.75 –.....	13.75 –.....	13.75 –.....

	Current Price	Last Month	Last Year
Wax, Bayberry, bbl., lb.	$0.16 –$0.20	$0.16 –$0.20	$0.20 –$0.22
Beeswax, ref., light, lb.	.25 – .27	.25 – .27	.26 – .30
Candelilla, bags, lb.	.14 –.....	.14 –.....	.13½– .14
Carnuba, No. 1, bags, lb.	.21½– .24	.23 – .24	.21½– .22
Paraffine, crude 105-110 m.p., lb.	.03½– .03¼	.03½– .04½	.03½– .03¾

Ferro-Alloys

	Current Price	Last Month	Last Year
Ferrotitanium, 15-18%, ton.	$200.00–.....	$200.00–.....	$200.00–.....
Ferromanganese, 78-82%, ton.	72.00–75.00	80.00–85.00	80.00–85.00
Ferrochrome, 65-70%.	.10–.....	.11–.....	.....–.....
Spiegeleisen, 19-21% ton.	27.00–.....	30.00–.....	30.00–.....
Ferrosilicon, 14-17%, ton.	31.00–.....	31.00–.....	39.00–.....
Ferrotungsten, 70-80%, lb.	1.00– 1.10	1.00– 1.10	1.10–.....
Ferrovanadium, 30-40%, lb.	3.05– 3.40	3.15– 3.50	3.15– 3.50

Non-Ferrous Metals

	Current Price	Last Month	Last Year
Copper, electrolytic, lb.	$0.05½–.....	$0.06½–.....	$0.10 –.....
Aluminum, 96-99%, lb.	.23–.....	.23–.....	.23–.....
Antimony, Chin. and Jap., lb.	.06 –.....	.06½–.....	.07½–.....
Nickel, 99%, lb.	.35 –.....	.35 –.....	.35 –.....
Monel metal blocks, lb.	.28 –.....	.28 –.....	.28 –.....
Tin, 5-ton lots, Straits, lb.	.18¼–.....	.22½–.....	.25 –.....
Lead, New York, spot. lb.	.03 –.....	.03½–.....	.045–.....
Zinc, New York, spot, lb.	.0317–.....	.0317–.....	.0435–.....
Silver, commercial, oz.	.28½–.....	.30½–.....	.28½–.....
Cadmium, lb.	.55 –.....	.55 –.....	.55 –.....
Bismuth, ton lots, lb.	.85 –.....	.85 –.....	1.25 –.....
Cobalt, lb.	2.50 –.....	2.50 –.....	2.50 –.....
Magnesium, ingots, 99%, lb.	.30 –.....	.30 –.....	.48 –.....
Platinum, ref., oz.	40.00 –.....	37.50 –.....	30.00–.....
Palladium, ref., oz.	19.00 – 21.00	19.00 – 21.00	19.00– 21.00
Mercury, flask, 75 lb.	73.00 – 75.00	70.00 –.....	102.00–.....
Tungsten powder, lb.	1.45 –.....	1.45 –.....	1.65–.....

Ores and Semi-finished Products

	Current Price	Last Month	Last Year
Bauxite, crushed, wks., ton.	$6.50 –$8.25	$6.50 –$8.25	$6.50 –$8.25
Chrome ore, c. f , post, ton.	17.00 –20.00	17.00 –20.00	19.50 –24.00
Coke, fdry., f.o b. ovens, t n.	3.25 – 3.75	3.25 – 3.75	2.75 – 2.85
Fluorspar, gravel, f.o.b. Il ., ton.	17.25 –20.00	17.25 –20.00	17.25 –20.00
Manganese ore, 50% Mn., c.i.f. Atlantic Ports, unit.	.25 – .26	.25 – .26	.25 – .27
Molybdenite, 85% MoS_2 per lb. MoS_2, N. Y., lb.	.45 –.....	.45 –.....	.35 – .40
Monazite, 6% of ThO_2, ton.	60.00 –.....	60.00 –.....	60.00 –.....
Pyrites, Span. fines, c.i.f., unit.	.13 –.....	.13 –.....	.13 –.....
Rutile, 94-96% TiO_2, lb.	.10 – .11	.10 – .11	.10 – .11
Tungsten, scheelite, 60% WO_3 and over, unit.	10.00 –10.50	10.50 –12.00	12.00 –12.50

CURRENT INDUSTRIAL DEVELOPMENTS

New Construction and Machinery Requirements

Ammonium Sulphate and Chemical Plant—South Manchuria Railway Co., Dairen, Manchuria, Asia, plans construction of an ammonium sulphate and chemical plant. Estimated cost $7,000,000. Maturity indefinite.

Plant—Benson Brass & Chandelier Works, E. B. Benson, V. Pres., 3888 East 63rd St., Kansas City, Mo., having preliminary plans prepared for rebuilding 2 and 3 story plant at 1417 Agnes St., destroyed by fire. Estimated cost $60,000.

Cement Plant—National Portland Cement Co., Finance Bldg., Philadelphia, Pa., will build a cement plant, power house and shops at Brodheadsville. Estimated cost $2,000,000. Work will be done by separate contracts. Maturity indefinite. A. P. Houser, Emaus, in charge.

Chemical Manufacturing Plant — Merck & Co. Inc., Lincoln Ave., Rahway, N. J., awarded contract for a 1 and 2 story addition to chemical manufacturing plant to Robert E. Lamb Co., 841 North 19th St., Philadelphia. Estimated cost $150,000.

Chemical Plant, etc. — City Commissioners, A. G. Graves, Comr., City Hall, Calgary, Alta., will soon award contract for construction and completion of a heating and chemical plant, pumping station and screen house for Glenmore Dam, Cont. 12. Gore, Nasmith & Storrie, Calgary, are consulting engineers.

Chlorine Machine — Mayor and Board of Aldermen, Leonoir City, Tenn., plans to purchase a secondary chlorine machine for use in waterworks system.

Clay Products Plant—Westfield Clay Products Co., Westfield, Mass., plans to rebuild plant destroyed by fire. Estimated cost $40,000. Private plans.

Clay Working and Ceramics Building—Board of Education, State Office Bldg., Albany, N. Y., constructing new building for State School of Clay-Working and Ceramics at Alfred University, for introduction of steam from central heating plant to old ceramics building and agricultural school buildings, also reconstructing greenhouses which were removed in order to erect ceramics building. $154,485. Bill was signed by the governor.

Mill—Miami Copper Co., F. W. Maclennan, Gen. Mgr., Miami, Ariz., has work under way on construction of a 3,000 ton mill by day labor. Estimated cost $50,000.

Mill—National Exploration Co., W. W. Linesba, Gen. Mgr., Prescott, Ariz., plans constructing a new 150 ton mill and installing equipment including crushers, ball mill, classifiers, thickeners and filters, ore bins, etc. Estimated cost $50,000.

Cotton Gin Plant—Jacksboro Gin, c/o A. Brown, Mgr., Jacksboro, Tex., plans construction of a cotton gin plant. Private plans. Interested in quotations on machinery and equipment including gas or gasoline engine, gin stands, feeder and huller.

Cotton Oil Mill—Independent Cotton & Oil Co., Mesa, Ariz., plans to rebuild cotton oil mill recently destroyed by fire. Estimated cost $75,000. Architect not announced.

Dye Plant—Radience Piece Dye Works, Inc., Third Ave., Paterson, N. J., awarded contract for a 1 and 2 story, 100 x 190 ft. addition to dye plant at Third Ave. and 26th St., to James Suseno, 115 Pine St., Paterson. $40,000.

Enameling and Plating Plant—Lighting Appliance Co., 9 Desbrosses St., New York, N. Y., Montreal, Que., has leased Dominion Rubber Co. plant at Montreal, Que., and will install equipment for enameling and plating plant.

Gas Plant—United Soviet Socialist Russia, c/o Amtorg Trading Corp., 261 5th Ave., New York, N. Y., will build an artificial gas plant in Leningrad district, also service lines for 12,500 apartment buildings. Estimated total cost $6,700,000. Work will be done by day labor and technical aid contracts.

Gas Purifier—Metropolitan Utilities District, 18th and Harney Sts., Omaha, Neb., will soon award contract for construction of a gas purifier capable of eliminating sulphuric impurities from 20,000,000 cu.ft. of gas daily. $62,000. C. D. Robinson, 18th and Harney Sts., Omaha, is engineer.

Gypsum Mill—Jumbo Plaster Mill, Siguard, Utah, c/o J. Greenwood, Salt Lake City, Dir., awarded structural steel contract for reconstruction of gypsum mill destroyed by fire to Provo Foundry & Machine Co., Provo. Estimated cost of mill complete and installation of new equipment $250,000.

Gypsum Plant—North American Gypsum Co. Ltd., Baddock, Nova Scotia, plans construction of a gypsum plant. Estimated cost $150,000.

Laboratory Equipment—Rochester & Pittsburgh Coal Co., Church and Carpenter Sts., Indiana, Pa., plans remodeling office building into laboratory building and will install new laboratory equipment. George Smith, Maple and Oakland Ave., Indiana, in charge.

Laboratory—Dominion Biological Branch of Department of Fisheries, A. G. Huntsman, Dir., St. Andrews, N. B., plans re-erection of laboratory building. Estimated cost including equipment $85,000.

Laboratory—John B. Pierce Foundation, c/o H. G. Ullman, 35 Oakland Ave., Yonkers, N. Y., completing plans for a 2 story, 45 x 58 ft. laboratory at Liberty St. and Congress Ave., New Haven, Conn. Estimated cost $40,000. H. L. Quick, 18 Getty Sq., Yonkers, is architect.

Laboratory—University of Richmond, Richmond, Va., awarded contract for construction of new biology building including taxidermic preparation department, comparative anatomy laboratory, etc., to A. F. Perrin, Richmond. Estimated cost $125,000.

Laboratory (Astrographic)—Bureau of Yards & Docks, Navy Department, Washington, D. C., received lowest bid for construction of a 3 story, 37 x 60 ft. building including laboratories, offices and lecture room for Naval Observatory, from Bahen & Wright, 916 Rhode Island Ave. N. E., Washington, D. C., $32,250.

Laboratory (Photographic)—Cardinell Vellum Mfg. Co., 15 Label St., Montclair, N. J., having plans prepared for construction of a 1 and 2 story photographic building, at Chicago, Ill. Estimated cost $50,000. Holabird & Root, 333 North Michigan Ave., Chicago, are architects.

Laboratories — F. S. Kolar, Wichita, Kan., having preliminary sketches made for a 3 story, 80 x 130 ft. hospital building including laboratories, X-ray room, etc. Estimated cost $75,000. T. Mason, Wichita, is architect.

Lye Plant—Owner, c/o B. T. Babbitt Co., 386 4th Ave., New York, N. Y., lessee, having plans prepared for construction of a plant at Toronto, Ont. Estimated cost including equipment $40,000. Lessee will purchase equipment.

Mine Development—Tavern Rock & Sand Co., 905 Wall St., Toledo, O., subsidiary of Illinois Owens Glass Works, 402 West Randolph St., Chicago, Ill., plans development of mines for glass sand on 275 acre site at Ashland, Ky., including mining machinery.

Paint and Varnish Plant—E. I. du Pont de Nemours & Co., Du Pont Bldg., Wilmington, Del., having plans prepared for a 68 x 155 ft. addition to paint and varnish plant at Philadelphia, Pa. Estimated cost, including equipment, $350,000. Maturity about June.

Pigment Plant—Titanium Pigment Co., c/o W. F. Meredith, 60 John St., New York, N. Y., plans construction of a plant, machine shop, etc., at South Amboy, N. J. Estimated cost $1,000,000.

Paper Mill—Commercial Pulp & Paper Co., Orange, Tex., purchased properties of Yellow Paper Mill and plans renovating and repairing same including new equipment. Estimated cost $75,000. Work will be done by owner's forces. C. A. Kieren, superintendent.

Paper Plant — Cleveland Wax Paper Co., 13831 Triskett Road, Cleveland, O., subsidiary of Detroit Wax Paper Co., Pleasant St. and New York Central R.R., Detroit, Mich., plans addition to wax paper plant at Cleveland. Estimated cost including equipment $40,000.

Paper Plant — Hammermill Paper Co., H. Schatain, East Lake Road, Erie, Pa., will soon award contract for construction of a 1 story, 130 x 260 ft. factory on East Lake Road. Estimated cost $100,000. Private plans. Bids April 4.

Paper Plant—Standard Wall Paper Co., Hudson Falls, N. Y., plans construction of a plant at Montreal, Que.

Paper Plant Addition—Paterson Parchment Paper Co., 35 8th St., Passaic, N. J., awarded contract for construction of a 90 x 200 ft. addition to paper plant at Edgely, Pa., to F. G. Pittet Construction Co., 9 Colt St., Paterson, N. J. $40,000.

Potash Deposits, etc.—U. S. Potash Co., 342 Madison Ave., New York, N. Y., plans potash deposits, shops and refinery at Loving, N. M. Estimated cost to exceed $800,000. Work will be done by separate contracts under the supervision of owners.

Processing Plant — Peerless Woolen Mills, Rossville, Ga., will build a 3 story, 100 x 300 ft. warehouse and processing plant. Estimated cost $100,000. W. H. Sears, James Bldg., Chattanooga, Tenn., is architect. Former bids rejected. Work by day labor and separate contracts.

Radium Extraction Plant — Eldorado Gold Mines, Ltd., 319 Bay St., Toronto, Ont., plans construction of a radium extraction plant at Great Bear Lake, Athabaka landing, to include crushing and grinding machinery chemical equipment, etc., also establishing barge transportation between deposits and Athabaka landing. Estimated cost to exceed $40,000. A. N. Pochon, c/o owner, is architect.

Rayon Plant Addition—Industrial Rayon Co., H. S. Rivitz, Pres., West 98th St. and Walford Road, Cleveland, O., awarded contract for a 1 story, 80 x 430 ft. addition to factory to George A. Rutherford Co., 2725 Prospect Ave., Cleveland. Estimated cost $150,000.

Refinery—California-Texas Leasing Co., J. F. Sadler, 810 South New Hampshire Ave., Los Angeles, Calif., and Presidio Petroleum Co., Presidio, Tex., c/o H. W. Rowe, Midland, plan construction of a refinery at Topolobampo, Mexico, to include pipe line from Midland to Topolobampo. Private plans. Topolobampo is the largest land locked harbor in the world.

Refinery—Walter K. Campbell, Wichita Falls, Tex., plans construction of a refinery to handle 400 bbl. of crude oil daily. Will install for lubricating unit now and later a cracking unit at McAllen, also building pipe line for transporting oil to Missouri Pacific Ry. right-of-way. Private plans.

Refinery — Mexican Petroleum Corp., 122 East 42nd St., New York, N. Y., having plans prepared for addition to refinery at Carteret, N. J. Estimated cost to exceed $40,000.

Refinery—Minister of Agriculture de Tomaso, Buenos Aires, Argentina, plans to expend $1,250,000 for construction of a refinery at La Plata, for preparation of lubricants which will handle 400 tons of crude oil daily.

Refinery Addition—Sterling Refining Co., c/o B. F. Green, Hunt Bldg., Tulsa, Okla., plans addition to and enlarging refinery and cracking stills at Oklahoma City. Estimated cost $40,000.

Refinery Addition—Utah Oil Refining Co., Newhouse Bldg., Salt Lake City, Utah, having preliminary plans prepared for additions and alterations to refinery including installation of a new type gasoline absorption plant and revision of refining equipment. Estimated cost $400,000. E. S. Holt, Salt Lake City, is engineer.

Refinery (Oil)—Alco Products Co., 220 East 42nd St., New York, N. Y., has been awarded contract for design and construction of an oil refinery at Midland, Mich. Estimated cost to exceed $350,000. Owner's name withheld. Equipment purchased by contractor.

Refineries — Midwest Refining Co., Casper, Wyo., awarded contract for electrifying Midwest and Standard refineries to Stearns-Rogers Mfg. Co., 1720 California St., Denver, Colo. $150,000.

Rubber Products Manufacturing Plant—Bata Ltd, Zlin, Czechoslavakia, plans construction of a rubber products manufacturing plant at Vuquvar, Yugoslavia. Estimated cost to exceed $40,000.

Stove Plant and Foundry—Athens Stove Works, Athens, Ga., awarded contract for construction of a 1 story, 125 x 200 ft. addition to plant and foundry to Nicholson Construction Co., 102 West Clinch Ave., Knoxville, Tenn. $40,000.

Sugar Refinery—British Columbia Sugar Refining Co. Ltd., Ft. Rogers, Vancouver, B. C., plans addition to beet sugar refinery at Raymond, Alberta. Estimated cost $250,000. Maturity indefinite.

Sugar Refinery—Fellsmere Sugar Co., Fellsmere, Fla., plans a 1 story addition to cane sugar refinery. $40,000. Work will be done by day labor.

Sugar Refinery—United Soviet Socialist Russia, Commissariat for Internal Supply, c/o Amtorg Trading Corp., 261 5th Ave., New York, N. Y., plans mechanization in 1932 of all state sugar-belt cultivation, also constructing plants for production of sugar from corn, chicory, soy bean and other raw materials. Maturity 1934.

Soap Manufacturers—Stone & Webster Engineering Co., 49 Federal St., Boston, Mass., Engrs., will soon award all contracts for construction of a 4 story soap factory at Hammond, Ind., for Lever Bros., Hammond. $500,000.

Sulphite Pulp Mill—F. L. Buckley, 510 West Hastings St., Vancouver, B. C., plans establishment of a bleached Swedish sulphite pulp mill at Prince Rupert, 200 ton daily capacity using approximately 700,000 ft. of logs daily.

Vermiculite Mine Development—E. F. Gobatti Engineering & Machinery Co., 311 South Victoria Ave., Pueblo, Colo., and Non-Metallic Corp., Chicago, Ill., joint owners, plan a vermiculite mine development including buildings, machinery, roads, etc., thirty miles southwest of Pueblo. Work will be done by owner's forces.

INDUSTRIAL NOTES

C. O. BARTLETT & SNOW Co., Cleveland, Ohio, has transferred P. W. Ross from the Philadelphia office to New York City, where he will be associated with W. H. Norrington.

KENNEDY VALVE MANUFACTURING Co. has moved its Chicago branch office and warehouse to 1306 South Canal St.

COLUMBIA ELECTRIC MANUFACTURING Co., Cleveland, Ohio, has formed an electrochemical division under F. G. Cyrex, manager and chief engineer.

VERONA CHEMICAL Co., Newark, N. J., has instituted a consulting chemical service ranging from laboratory research to factory production.

GRAVER TANK & MANUFACTURING Co., East Chicago, Ind., has appointed W. K. Evans as general sales manager.

WORTHINGTON PUMP & MACHINERY CORP. has appointed Frank R. Wheeler special representative for the Middle West at its Chicago office.

CONHART REFRACTORIES Co., Louisville, Ky., has appointed Emsco Refractories Co., of Los Angeles, as its West Coast representative.

LOUIS ALLIS Co., Milwaukee, Wis., has appointed Sterling Electric Motors, Inc., as Pacific Coast representative at Los Angeles and San Francisco.

ALCO PRODUCTS, INC., a division of the American Locomotive Co., has acquired the entire business of Jackson Engineering Corp., Tulsa, Okla.

LUKENWELD, INC., a division of Lukens Steel Co., Coatesville, Pa., has appointed W. S. Wilbraham as assistant manager of sales.

WATSON-STILLMAN Co., Roselle, N. J., has appointed the Spalding Machinery Co., Inc., 205 West Wacker Drive, Chicago, its representative in that territory.

MACKINTOSH-HEMPHILL Co., Pittsburgh, Pa., has elected J. F. Ervin president.

DINGS MAGNETIC SEPARATOR Co., Milwaukee, Wis., has appointed J. M. Lee its representative at 114 West 17th St., Los Angeles, Calif.

DUST RECOVERING & CONVEYING Co., Cleveland, Ohio, has formed a foreign business department represented by the Power Gas Corp., Ltd., Stockton-on-Tees, England, and Tevo, Ltd., Brussels, Belgium.

T. W. CAMPBELL Co., INC., has moved its offices to 157 Chambers St., New York City.